Final Report
Phase I RCRA Facility Investigation for Appendix I Sites
VOLUME VII

SWMU-1, Landfill No. 6
SWMU-2, Landfill No. 5
SWMU-3, Landfill No. 1
SWMU-4, Landfill No. 2
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SWMU-6, Landfill No. 4

Department of the Air Force
Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma

September 1994

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RFI REPORT

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VOLUME VII

SWMU-1, Landfill No. 6

Department of the Air Force
Oklahoma City Air Logistics Center
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List of Acronyms

AFB	Air Force Base
AOC	area of concern
BEMO	Battelle Environmental Management Operations
BTEX	benzene, toluene, ethyl benzene, and xylene
CAL	Corrective Action Level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CDM	CDM Federal Programs Corporation
CFR	Code of Federal Regulations
CMS	Corrective Measures Study
cm/s	centimeters per second
DERP	Defense Environmental Restoration Program
DOD	U.S. Department of Defense
DWS	drinking water standards
EC	electric conductivity
EID	Engineering Installation Division
EPA	U.S. Environmental Protection Agency
ES	Engineering Science
FS	feasibility study
ft/ft	foot per foot
IRP	Installation Restoration Program
IT	IT Corporation
LSZ	lower saturated zone
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level
NAAQS	National Ambient Air Quality Standards
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPL	National Priorities List
PA/SI	preliminary assessment/site investigation
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study

RFI	RCRA Facility Investigation
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TCE	trichloroethene
TDS	total dissolved solids
TSD	treatment, storage, and disposal (facility)
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers
USC	U.S. Code
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USZ	upper saturated zone
UWBZ	upper water bearing zone
VOC	volatile organic compounds
WQS	Water Quality Standards
yd^3	cubic yards

Executive Summary

This report provides a summary of the various investigations that have been conducted at the solid waste management unit (SWMU)-1, Landfill No. 6 (Landfill 6), Tinker Air Force Base (AFB), Oklahoma. This report has been prepared to determine and document whether sufficient investigations have been performed at Landfill 6 to meet regulatory requirements. Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County. The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. The Base encompasses approximately 5,000 acres.

Background. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon^{TM}, jet fuels, and radium paints.

In 1984, Congress amended the Resource Conservation and Recovery Act (RCRA) with the Hazardous and Solid Waste Amendments (HSWA), which allow EPA to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or contaminants from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989, Tinker AFB submitted its Part B permit application for renewal of its operating RCRA Hazardous Waste Storage facility permit. The final RCRA HSWA permit issued on July 1, 1991, requires Tinker AFB to investigate all SWMUs and areas of concern (AOC) and to perform corrective action at those identified as posing a threat to human health and the environment. The permit specifies that a RCRA Facility Investigation (RFI) be conducted for 43 identified SWMUs and two AOCs on the Base. This document has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 6.

Source Description. Landfill 6 is located on land leased from Oklahoma City and is adjacent to the western edge of the Engineering Installation Division (EID), also referred to as Area D. The EID and Landfill 6 are located on Southeast 59th Street, approximately one-half mile east of Tinker AFB.

Landfill 6 was operated from 1970 to 1979. Records indicate that the site was used for the disposal of general refuse, industrial refuse, and sludges from industrial wastewater treatment plants. General refuse consisted of items such as paper, lumber, leaves, branches, food, and household wastes. Disposal of industrial waste material consisted of items such as paint, insecticide, and solvent containers. Approximately 500,000 cubic yards (yd^3) of waste material, in total, was disposed of in the landfill during its operating history. Although 40 acres were available at the site, only about 25 acres were used by the landfill prior to closing in 1979. Trenches in the western half of the landfill were filled with refuse, as well as two additional trenches in the eastern half, adjacent to Southeast 59th Street.

Site Investigations. A number of studies (Engineering Science [ES], 1982; Radian Corporation [Radian], 1985a,b; CH2M Hill, 1986; U.S. Army Corps of Engineers [USACE], 1993a; CDM Federal Programs Corporation [CDM], 1992) have been conducted at Landfill 6, for various objectives. One of these objectives was to determine the nature and extent of contamination potentially introduced into the environment as a result of past waste disposal practices at Landfill 6.

Soils. Background soil concentrations for trace metals were determined based on a study performed by the U.S. Geological Survey (USGS) (1991). The USGS study provided metals analysis for 293 soil samples taken over at four-county area in central Oklahoma with Tinker AFB at the approximate center of the study site. Site-specific metal analyses from soil samples were compared to background levels as presented in the USGS study.

During RI activities performed by the USACE under the IRP, samples were obtained from 20 soil borings drilled into the landfill trenches at Landfill 6. Although the samples contained waste products representative of the disposed waste material, they were also samples of the soil cover material used daily to cover and compact the deposited wastes. The soil samples were analyzed for metals, total organic carbon (TOC), cyanide, pH, electric conductivity (EC), volatile organic compounds (VOC), semivolatile organic compounds (SVOC), and pesticides (USACE, 1993a). VOCs, SVOCs, and cyanide were detected sporadically and with varying concentrations throughout the landfill. Metals and TOC were also detected throughout the landfill with varying concentrations.

Groundwater. Groundwater beneath Landfill 6 has been investigated through the installation and sampling of several groundwater monitoring wells located throughout the site. As a result of several phases of investigation, a total of 18 monitoring wells have been installed to monitor the upper saturated zone (USZ). USZ groundwater within five of the landfill trenches was also sampled on a one-time basis during the USACE's remedial investigation (RI) activities. The saturated zone beneath the USZ, identified as the lower saturated zone (LSZ), has been investigated through the installation and sampling of 14 monitoring wells.

From 1986 through 1987, groundwater samples from available wells were analyzed for total and dissolved metals, TOC, oil and grease, chloride, sulfate, cyanide, pH, EC, VOCs, SVOCs, and pesticides. Sampling of all available monitoring wells was performed again in August through October 1988, and then again in September 1989. These samples were analyzed for total metals, TOC, chloride, sulfate, cyanide, pH, EC, VOCs, and SVOCs.

As a result of the 1991 focused RI performed by CDM, six newly installed and six existing wells were sampled for chloride, sulfate, and TDS in August 1991 and again in April 1992. Additional sampling of select groundwater monitoring wells was performed in October and November 1991 by CDM as a result of a separate groundwater monitoring program for Tinker AFB. Sampling of all wells was again performed in 1992 and 1994 under the Long-Term Monitoring of Groundwater Quality Program (Weston, 1993).

Trench Water. Several metals, VOCs, and SVOCs were detected in the trench water samples. Concentrations of cadmium, trans-1,2-dichloroethene, and 1,2-dichloropropane exceeded maximum contaminant levels (MCL), and cadmium, lead, and chromium concentrations exceeded the SWMU corrective action levels (CAL) in the trench water.

USZ. The majority of groundwater contamination in the USZ was found to be in the western portions of the landfill site. The primary metal contaminants were arsenic, barium, cadmium, chromium, lead, and nickel, with barium having the highest frequency of occurrence and concentration. Arsenic, cadmium, lead, and nickel concentrations exceeded the MCLs and SWMU CALs in several samples.

VOCs and SVOCs were sporadically detected throughout the USZ. Methylene chloride, acetone, 1,1-dichloroethane, trichloroethene, and fuel-related compounds are the primary VOCs at the site. The primary SVOCs detected at the site were bis(2-ethylhexyl)phthalate, di-n-octyl phthalate, diethyl phthalate, and 1,4-dichlorobenzene. These compounds were considered primary due to the frequency and concentrations throughout the site.

Methylene chloride, bis(2-chloroethyl)ether, bis(2-ethylhexyl)phthalate, cis-1,2-dichloroethene, and tetrachloroethene concentrations exceeded the SWMU CALs, and 1,2-dichloroethane, benzene, trichloroethene, and vinyl chloride concentrations exceeded the MCLs in several samples.

TOC and chloride also appeared in elevated levels in the USZ. The wells with higher TOC concentrations are located to the west of the landfill trenches.

Lower Saturated Zone. Nickel concentrations exceeded the SWMU CAL, and cadmium, chromium, lead, and barium concentrations exceeded the MCLs in several samples. VOCs and SVOCs were also detected sporadically in the LSZ. Methylene chloride, bis(2-ethylhexyl)phthalate, and tetrachloroethene concentrations exceeded the SWMU CALs, and benzene and trichloroethene exceeded the MCLs in several samples.

Sediments. Stream sediment from a tributary to Stanley Draper Lake was sampled in 1986 as a part of the RI activities conducted by the USACE. Six samples were taken from the stream bottom along the eastern and southern sections of the stream to investigate any contamination of the creeks near Landfill 6. Sediment samples were analyzed for total metals, TOC, cyanide, pH, EC, VOCs, SVOCs, and pesticides.

Arsenic, barium, chromium, and selenium were detected in all of the sediment samples. However, only selenium was detected above background in all the samples. Methylene chloride and acetone were the only organic compounds detected in relatively high concentrations, but none exceeded the action levels.

Conclusions. The various investigations conducted at Landfill 6 confirmed and concluded that the USZ underneath the site was primarily contaminated with metals and organic constituents leached from the landfill. Aquifer contamination was mainly concentrated in the western part of the landfill as a result of groundwater flow in the westerly direction. The deeper LSZ groundwater was found to be contaminated with both metals and some organic but to a lesser extent as compared to the USZ. The source of contamination in the lower aquifer was attributed to downward migration of the contaminated groundwater from the USZ.

Evaluation of current and previously collected data confirms the previous studies in concluding that contaminants have migrated away from the site. The concentration levels of these contaminants in downgradient wells exceeds the action levels. This condition indicates a need for a Corrective Measure Study (CMS) to be undertaken as soon as possible. Groundwater monitoring also should be continued to keep track of contaminant migration.

Recommendations. Based on the data evaluations, there is evidence of contaminant migration away from the site. The presence of these constituents in downgradient wells at concentration levels exceeding the action levels indicates a need for a CMS of the releases from Landfill 6 be undertaken immediately. The CMS is intended to provide sufficient data necessary for developing a corrective action plan (CAP) to remediate the releases from the site. The CAP will involve identifying potential remedial alternatives that will:

- Prevent further migration of the groundwater plume.
- Remediate or stabilize the source of groundwater contamination north of Landfill 6.

It is recommended that the following be implemented:

- A CMS be conducted as soon as possible to remediate the release of the contaminants from the landfill.
- Groundwater monitoring be continued in the downgradient wells, MW-63, MW-64, MW-65, MW-66, and MW-67 to keep track of contaminant migration while the CMS is underway.
- Collect site-specific soil background samples to be used in addition to USGS soil data to distinguish site-related from background concentrations in a statistically significant manner during the Phase II investigation.

1.0 Introduction

1.1 Purpose and Scope

This document has been prepared in response to the U.S. Department of the Air Force, Tinker Air Force Base (AFB), Oklahoma request for a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Summary Report for solid waste management unit (SWMU)-1, Landfill No. 6 (Landfill 6).

The objective of this RFI Summary Report is to provide Tinker AFB with one comprehensive report that summarizes the various investigations that have occurred at Landfill 6 since the first environmental investigation was initiated on Base in 1981. The purpose of this comprehensive summary document is to:

- Characterize the site (Environmental Setting).
- Define the source (Source Characterization).
- Define the degree and extent of contamination (Contamination Characterization).
- Identify actual or potential receptors.
- Identify all action levels for the protection of human health and the environment.

Additionally, this document briefly describes the procedures, methods, and results of all previous investigations that relate to Landfill 6 and contaminant releases, including information on the type and extent of contamination at the site, and actual or potential receptors. Where previous investigations, reports, or studies were not comprehensive and did not furnish the information required to determine the nature and extent of contamination, future work that can be conducted to complete the investigation has been recommended.

1.2 Preface

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to address the cleanup of hazardous waste disposal sites across the country. CERCLA gave the president authority to require responsible parties to remediate the sites or to undertake response actions through use of a fund (the Superfund). The president, through Executive Order 12580, delegated the U.S. Environmental Protection Agency (EPA) with the responsibility to investigate and remediate private party hazardous waste disposal sites that created a threat to human health and the environment. The president delegated responsibility for investigation and cleanup of federal facility disposal sites to the various federal agency heads. The Defense Environmental Restoration Program (DERP) was formally established by Congress in Title 10 U.S. Code (USC) 2701-2707 and 2810. DERP provides centralized management for the cleanup of U.S. Department of Defense (DOD) hazardous waste sites consistent with the provisions of CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations [CFR] 300), and Executive Order 12580. To support the goals of DERP, the Installation Restoration Program (IRP) was developed to identify, investigate, and clean up contamination at installations.

Under the Air Force IRP, Tinker AFB began a Phase I study similar to a preliminary assessment/site investigation (PA/SI) in 1981 (Engineering Science [ES], 1982). This study helped locate 14 sites that needed further investigation. Phase II studies were performed in 1983 (Radian Corporation [Radian], 1985a,b).

In 1986, Congress amended CERCLA through SARA. SARA waived sovereign immunity for federal facilities. This act gave EPA authority to oversee the cleanup of federal facilities and to have the final authority for selecting the remedial action at federal facilities placed on the National Priorities List (NPL) if the EPA and the relevant federal agency cannot concur in the selection. Congress also codified DERP (SARA Section 211), establishing a fund for the DOD to remediate its sites because the Superfund is not available for the cleanup of federal facilities. DERP specifies the type of cleanup responses that the fund can be used to address.

In response to SARA, the DOD realigned its IRP to follow the investigation and cleanup stages of the EPA:

- PA/SI
- Remedial investigation/feasibility study (RI/FS)
- Record of Decision (ROD) for selection of a remedial action
- Remedial design/remedial action.

In 1984, Congress amended RCRA with the Hazardous and Solid Waste Amendments (HSWA) which allow the EPA to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or constituents from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989 Tinker AFB submitted its Part B permit application for renewal of its operating RCRA hazardous waste storage facility permit.

EPA, in the Hazardous Waste Management Permit for Tinker AFB, dated July 1, 1991, identified 43 SWMUs and two areas of concern (AOC) on Tinker AFB that need to be addressed. This permit requires Tinker AFB to investigate all SWMUs and AOCs and to perform corrective action at those identified as posing a threat to human health or the environment. This RFI Summary Report has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 6 and to document all determinations.

1.3 Facility Description

Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County (Figure 1-1) with its approximate geographic center located at 35° 25' latitude and 97° 24' longitude (U.S. Geological Survey [USGS], 1978). The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. An additional area east of the main Base is used by the Engineering Installation Division (EID) and is known as Area D. The Base encompasses approximately 5,000 acres. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon™, jet fuels, and radium paints. Wastes that are currently generated are managed at two permitted hazardous waste storage facilities. However, prior to enactment of RCRA, industrial wastes were discharged into unlined landfills and waste pits, streams, sewers, and ponds. Past releases from these landfills, pits, etc., as well as from underground tanks, have occurred. As a result, there are numerous sites of soil, groundwater, and surface water contamination on the Base.

The various reports generated as a result of investigative activities conducted at the Landfill 6 have been reviewed and evaluated in terms of the sites' status under RCRA regulations. A summary based on the review of these reports for Landfill 6 is presented in the following chapters and sections. In addition, recommendations for additional work is given at the end of the summary report.

1.4 Site Description

Landfill 6 is located on land leased from Oklahoma City and is adjacent to the western edge of the EID, also referred to as Area D. The EID is a research and support unit for Air Force

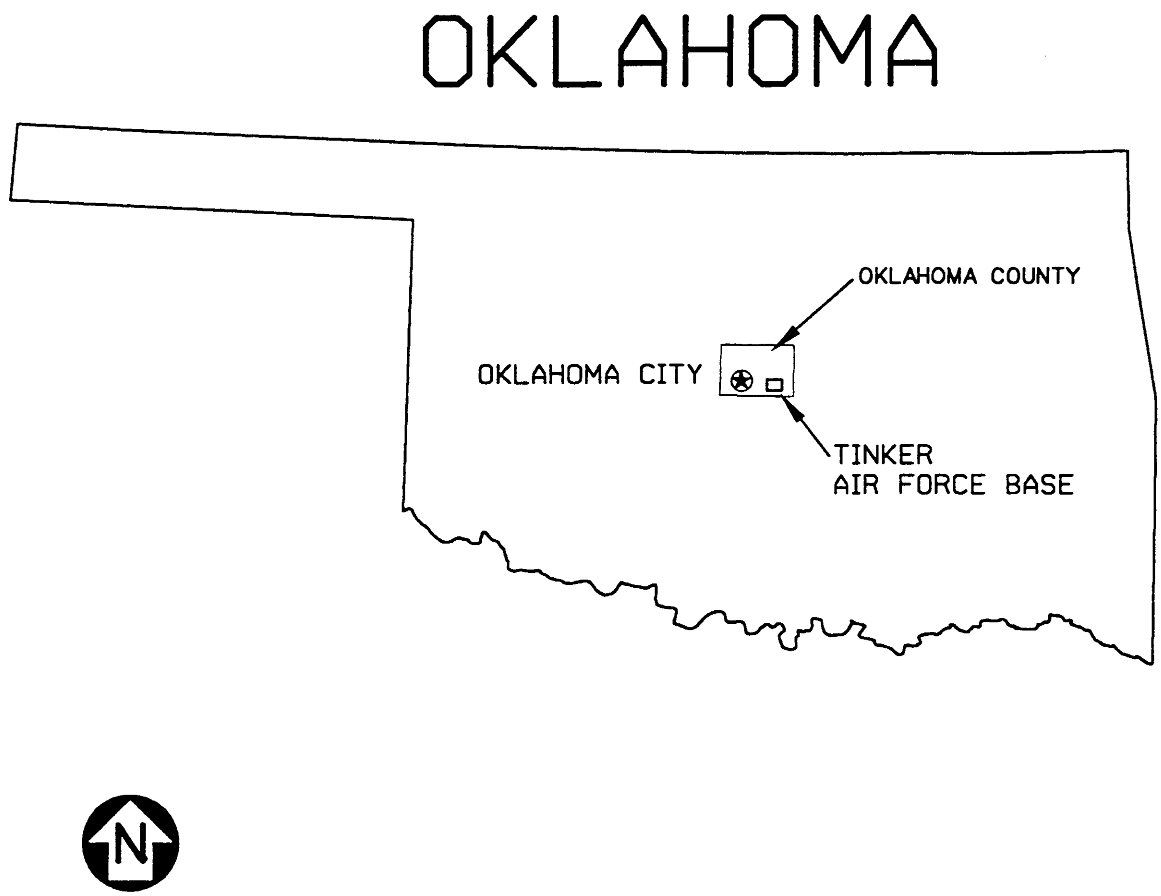


FIGURE 1-1
TINKER AIR FORCE BASE
OKLAHOMA
STATE INDEX MAP

PREPARED FOR
TINKER AFB
OKLAHOMA

STARTING DATE: 03/17/94	DATE LAST REV.:	DRAFT. CHCK. BY:G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY:P.O. TERRY	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.:J. TAYLOR	PROJ. NO.:

3/23/94 POT
FILENAME: G:\TINKER\40983202.075

communications and electronic engineering research and applications. The EID and Landfill 6 are located on Southeast 59th Street, approximately one-half mile east of Tinker AFB. A total of 40 acres was earmarked for the landfill, but only 25 acres were used for waste disposal. The location of Landfill 6 relative to the Base is shown in Figure 1-2.

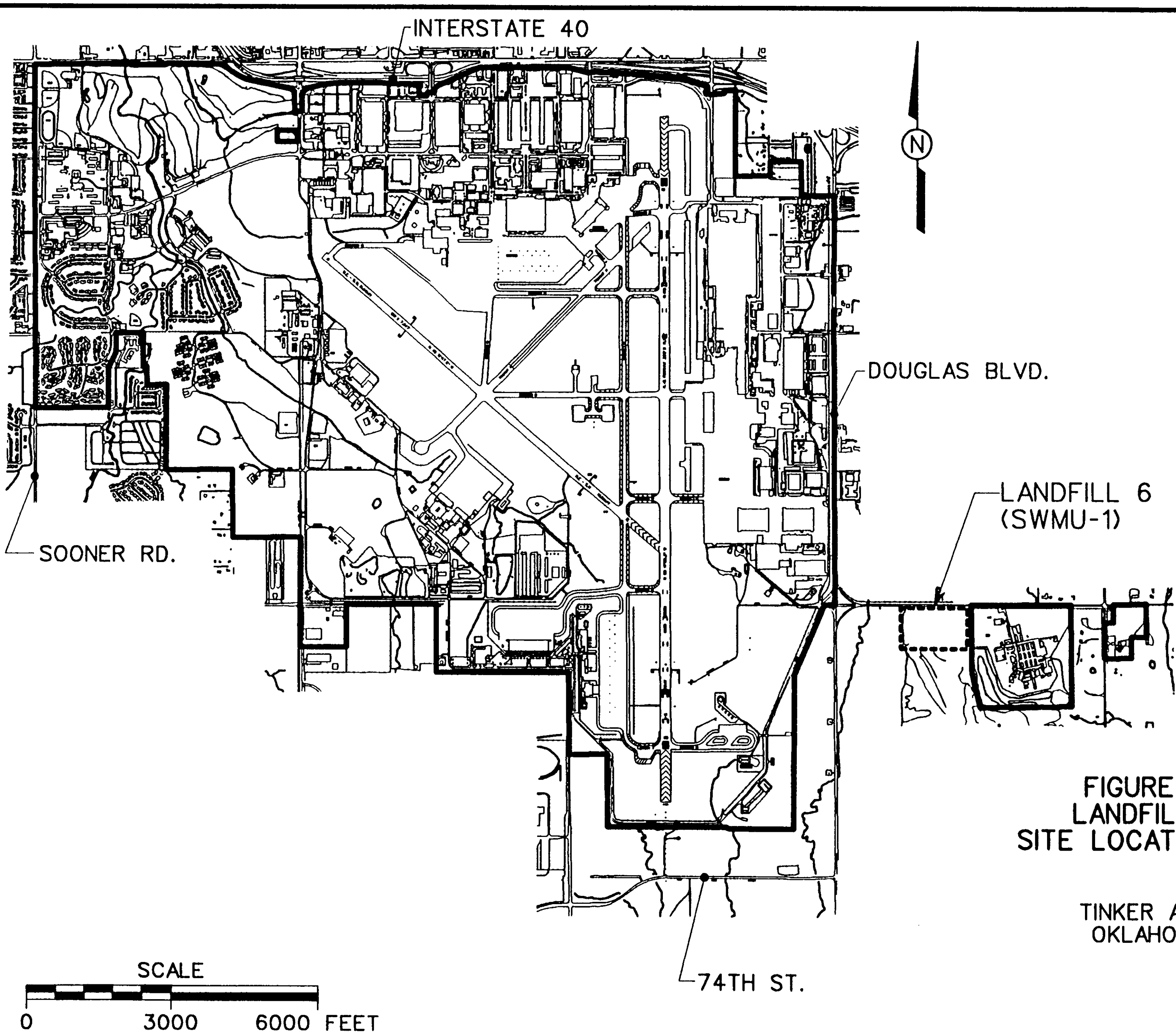


FIGURE 1-2
LANDFILL 6
SITE LOCATION MAP

TINKER AFB
OKLAHOMA

DRAWN BY: P.O. TERRY	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J. TAYLOR	PROJ. NO.:
STARTING DATE: 3/18/94	DATE LAST REV.:	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:

FILENAME: G:\TINKER\40983202.079

2.0 Background

2.1 Site Operations and History

Tinker AFB was originally known as the Midwest Air Depot and began operations in July 1941. The site was activated March 1942. During World War II, the depot was responsible for reconditioning, modifying, and modernizing aircraft, vehicles, and equipment.

General refuse generated from these operations has been disposed of in at least six landfills located on the Base property or leased land adjacent to the Base. One of these landfills, Landfill 6, is located on land leased from Oklahoma City.

Landfill 6 was operated from 1970 to 1979. Records indicate that the site was used for the disposal of general refuse, industrial refuse, and sludges from industrial wastewater treatment plants (U.S. Army Corps of Engineers [USACE], 1993a). General refuse consisted of items such as paper, lumber, leaves, branches, food, and household wastes. Disposal of industrial waste material consisted of items such as paint, insecticide, and solvent containers. Approximately 500,000 cubic yards (yd^3) of waste material, in total, was disposed of in the landfill during its operating history. Although 40 acres were available at the site, only about 25 acres were used by the landfill prior to closing in 1979. Trenches in the western half of the landfill were filled with refuse, as well as two additional trenches in the eastern half, adjacent to Southeast 59th Street.

2.2 Summary of Previous Investigations

Records Search, Installation Restoration Program, Phase I. Site investigations of Landfill 6 for the Tinker AFB IRP date back to the early 1980s. At that time, the Tinker AFB IRP initiated an investigation to determine the nature and extent of contamination at Landfill 6. Phase I, which was executed by ES, implemented a records search to review current and past waste disposal practices to evaluate potential sources of contamination. Also, during that time a private well (the Ainsworth Well) north of Landfill 6 was sampled and found to be contaminated by organic compounds. It was not determined whether Landfill 6 was the source of these contaminants (ES, 1982).

Field Evaluation, IRP Phase II, Stages 1 and 2. Phase II field investigations were initiated in 1983 by Radian Corporation (Radian, 1985a). The purpose of these efforts was to determine if any environmental contamination had occurred due to disposal and management practices at Landfill 6. Radian's field investigation reported the existence of a shallow perched aquifer (upper saturated zone [USZ]) at and just below the lower landfill trench boundaries. Radian also located the lower saturated zone (LSZ) beneath the landfill. Three shallow and three deep monitoring wells were installed to monitor the USZ and LSZ water quality. Numerous synthetic organic contaminants were found in samples collected from both aquifers.

Hydrogeologic Investigation. CH2M Hill was employed in 1986 to define in more detail the hydrogeology of the area surrounding Landfill 6. Two shallow and two deep wells were installed along the borders of the site. Three test borings were drilled to a depth of 150 feet to assess lithology beneath the site. The subsurface investigations reported the existence of several perched aquifers underlying and surrounding the site as a result of horizontal and discontinuous impeding shale layers. CH2M Hill investigations described infiltration of surface water to the regional aquifer as both vertical and horizontal flow, "cascading" as it bypasses these impermeable (impeding) layers (CH2M Hill, 1986).

Remedial Investigation Report. Between 1986 and 1990, Tinker AFB employed the USACE to conduct a remedial investigation of Landfill 6. USACE was to determine the nature and extent of contaminants and their possible migration route throughout the site. USACE investigations included a records search, ground-penetrating radar survey, stream sediment sampling, and the installation of 17 monitoring wells and 20 trench borings. Four soil borings around the Tinker AFB perimeter were taken to determine background levels of metals, volatile organic compounds (VOC), and semivolatile organic compounds (SVOC). Water and soil samples from the monitoring wells, trenches, and borings, and stream sediment samples were tested for total metals, total organic carbon (TOC), chloride, sulfate, pH, electric conductivity (EC), VOCs, and SVOCs.

Using the results from these tests, the USACE concluded that the perched USZ underneath the site was primarily contaminated with metal-laden leachate derived from Landfill 6. Those metals posing the greatest threat to groundwater quality (above drinking water standards [DWS]) were found to be arsenic, barium, cadmium, chromium, and lead.

USACE tests for the presence of volatile and semivolatile organics also indicated that several organic compounds had migrated from Landfill 6 and contaminated the underlying perched aquifer. These contaminants include methylene chloride; acetone; 1,1-dichloroethane;

trichloroethene (TCE); benzene, toluene, ethyl benzene, and xylene (BTEX); diethyl phthalate; bis(2-ethylhexyl)phthalate; di-n-octyl phthalate; diethyl phthalate; and 1,4-dichlorobenzene. Aquifer contamination was more concentrated underneath the western half of the landfill; this variation was attributed to the westward gradient of the perched aquifer.

The deeper LSZ was found to be contaminated with metals and organics to a lesser extent. The source of contamination in the lower zone was attributed to downward migration of contaminated groundwater from the perched water table within Landfill 6. Barium, cadmium, and chromium were the only contaminants exceeding DWSs. Organics detected include, methylene chloride, acetone, TCE, benzene, and toluene. The USACE estimated a westward contaminant plume migration rate of 70 feet per year.

The USACE surmised that the primary route of contaminant transport was through horizontal and vertical groundwater flow from the perched aquifer lying within and below the disposal trenches (USACE, 1993).

Focused Remedial Investigation Report. An investigation of Landfill 6 was conducted during 1991 and 1992 by CDM Federal Programs Corporation (CDM) under contract to Battelle Environmental Management Operations (BEMO). The purpose of this phase of work was to determine if a source upgradient of Landfill 6 could be contributing to elevated concentrations of chlorides, sulfates, and total dissolved solids (TDS) found in groundwater samples from monitoring wells at the site. CDM was tasked to assist BEMO with the technical support necessary to gather groundwater data for these ions and TDS concentrations upgradient of the landfill.

CDM's technical support consisted of the installation, development, and sampling of six wells upgradient of Landfill 6 and sampling six existing wells. Three of the new wells were installed in the lower aquifer zone, at depths between 99 and 120 feet below the ground surface. Three wells were installed in the USZ, at depths of 20 to 50 feet below grade. The new wells, plus the six existing wells at Landfill 6, were sampled on two separate field excursions to determine concentration levels of chloride, sulfate, and TDS. Field parameters measured included pH, oxidation reduction potential, conductivity, and temperature.

CDM's general conclusions, based on analytical data and analysis of groundwater flow patterns, were that upgradient sources were probably not responsible for the elevated levels of chloride, sulfate, and TDS (CDM, 1992).

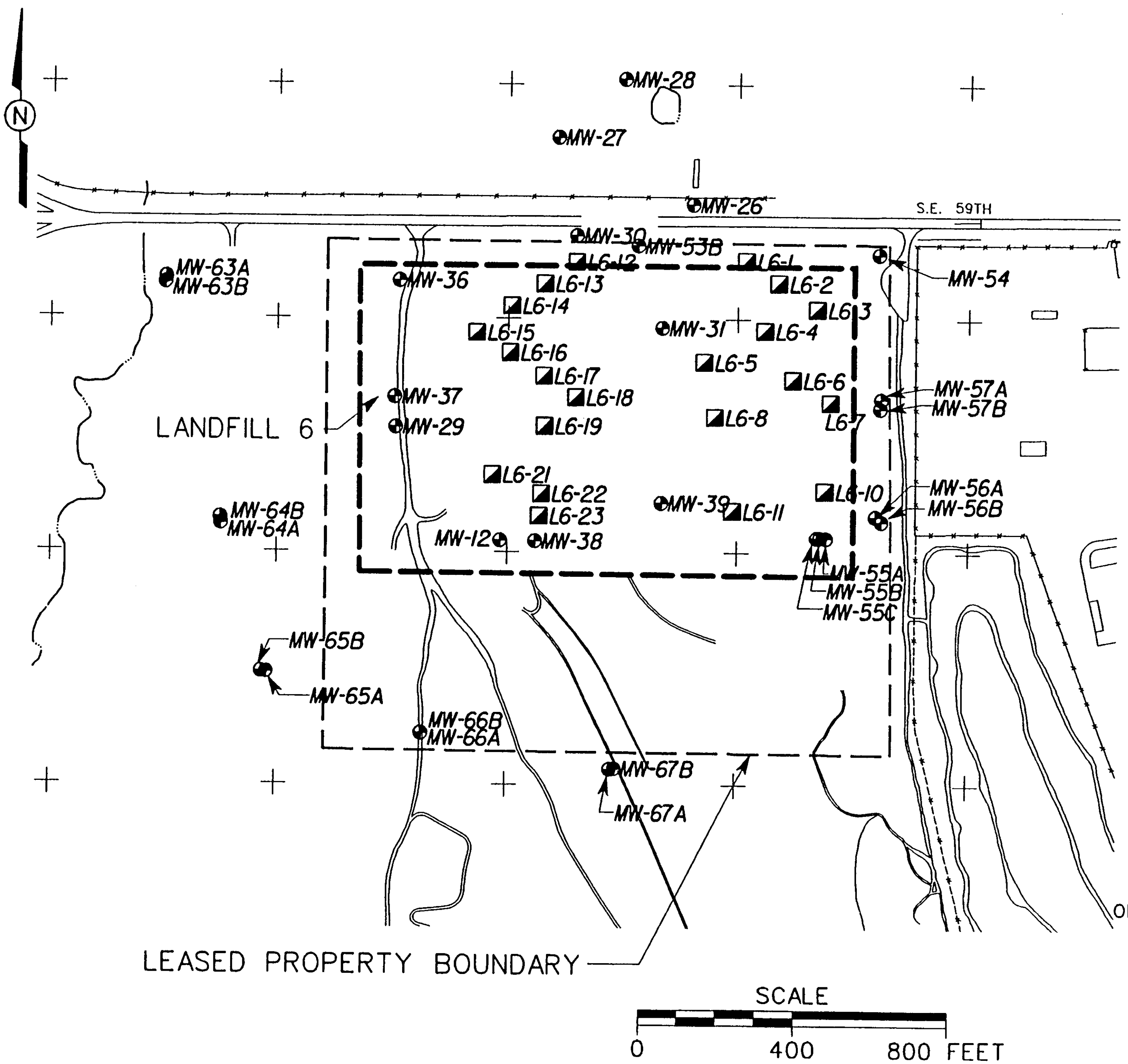
Groundwater Monitoring Program Sampling and Analysis. During October through November 1991, CDM sampled select groundwater monitoring wells from several sites at Tinker AFB. Included in this sampling schedule were 13 monitoring wells at Landfill 6. The report of findings (CDM, 1993) named several contaminants in the groundwater, confirming earlier reports of contamination due to inorganics and synthetic organic compounds migrating from the landfill into the groundwater. Figure 2-1 shows the locations of monitoring wells at Landfill 6.

Preliminary data is available from the February 1994 sampling event conducted under the Groundwater Monitoring Program. This data has been included within this report; however, this data is in preliminary draft form and has not undergone formal validation and is, therefore, subject to modification.

2.3 Current Regulatory Status

The IRP has been ongoing at Tinker AFB since the early 1980s. IRP studies on the Base were conducted according to IRP guidance, which is essentially the same as EPA's guidance for conducting RI/FS under CERCLA. All investigation and removal actions have been closely monitored and approved by the EPA.

Since receiving the Hazardous Waste Management Permit on July 1, 1991, many of the IRP sites have come under the jurisdiction of the RCRA permits branch of EPA. As such, they have been identified as SWMUs; however, a large amount of work has already been performed at most of these sites under the IRP. Additional investigation at the SWMUs will be performed under the IRP.



LEGEND:

MW-28 MONITORING WELL

L6-13 SOIL BORING

I-IS
I-ID

FIGURE 2-1

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 6
SITE LOCATION AND
SAMPLE LOCATION MAP

STARTING DATE: 01/14/94	DATE LAST REV.: / /	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P. TERRY	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

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3.0 Environmental Setting

3.1 Topography and Drainage

3.1.1 Topography

Regional/Tinker AFB. The topography of Oklahoma City and surrounding area varies from generally level to gently rolling in appearance. Local relief is primarily the result of dissection by erosional activity or stream channel development. At Oklahoma City, surface elevations are typically in the range of 1,070 to 1,400 feet mean sea level (msl). At Tinker AFB, ground surface elevations vary from 1,190 feet msl near the northwest corner where Crutcho Creek intersects the Base boundary to approximately 1,320 feet msl at Area D (EID).

Site. The Landfill 6 site is located on leased land just east of Tinker AFB and ranges in elevation from approximately 1,280 feet msl to 1,314 feet msl. The disposal area was located at the crest of a low hill, with drainage away from the site generally to the north before entering tributaries to Stanley Draper Lake.

3.1.2 Surface Drainage

Regional/Tinker AFB. Drainage of Tinker AFB land areas is accomplished by overland flow of runoff to diversion structures and then to area surface streams, which flow intermittently. The northeast portion of the Base is drained primarily by unnamed tributaries of Soldier Creek, which is itself a tributary of Crutcho Creek. The north and west sections of the Base, including the main instrument runway, drain to Crutcho Creek, a tributary of the North Canadian River. Two small unnamed intermittent streams crossing installation boundaries south of the main instrument runway generally do not receive significant quantities of Base runoff due to site grading designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

Site. Surface drainage in the vicinity of Landfill 6 is influenced by the engineered clay cap in place at the site. The cap was designed to divert surface drainage away from the landfill to a centrally located drainage ditch, as well as to ditches along the perimeter of the cap. Ultimately, surface drainage is intercepted by tributaries leading to Stanley Draper Lake, to the south of Tinker AFB.

3.2 Geology

3.2.1 Regional/Tinker AFB Geology

Tinker AFB is located within the Central Redland Plain Section of the Central Lowland physiographic province, which is tectonically stable. No major fault or fracture zones have been mapped near Tinker AFB. The major lithologic units in the area of the Base are relatively flat-lying and have a regional westward dip of about 0.0076 foot per foot (ft/ft) (Bingham and Moore, 1975).

Geologic formations that underlie Tinker AFB include, from oldest to youngest, the Wellington Formation, Garber Sandstone, and the Hennessey Group; all are Permian in age.

All geologic units immediately underlying Tinker AFB are sedimentary in origin. The Garber Sandstone and Wellington Formation are commonly referred to as the Garber-Wellington Formation due to strong lithologic similarities. These formations are characterized by fine-grained, calcareously-cemented sandstones interbedded with shale. The Hennessey Group consists of the Fairmont Shale and the Kingman Siltstone. It overlies the Garber-Wellington Formation along the eastern portion of Cleveland and Oklahoma counties. Quaternary alluvium is found in many undisturbed streambeds and channels located within the area.

Stratigraphy. Tinker AFB lies atop a sedimentary rock column composed of strata that ranges in age from Cambrian to Permian above a Precambrian igneous basement. Quaternary alluvium and terrace deposits can be found overlying bedrock in and near present-day stream valleys. At Tinker AFB, Quaternary deposits consist of unconsolidated weathered bedrock, fill material, wind-blown sand, and interfingering lenses of sand, silt, clay, and gravel of fluvial origin. The terrace deposits are exposed where stream valleys have downcut through older strata and have left them topographically above present-day deposits. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

Subsurface (bedrock) geologic units which outcrop at Tinker AFB and are important to understanding groundwater and contaminant concerns at the Base consist of, in descending order, the Hennessey Group, the Garber Sandstone, and the Wellington Formation (Table 3-1). These bedrock units were deposited during the Permian Age (230 to 280 million years ago) and are typical of redbed deposits formed during that period. They are composed of a conformable sequence of sandstones, siltstones, and shales. Individual beds are lenticular and vary in thickness over short horizontal distances. Because lithologies are similar and because

Table 3-1

Major Geologic Units in the Vicinity of Tinker AFB (Modified from Wood and Burton, 1968)

(Page 1 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	PLEISTOCENE	Alluvium	0-70	Unconsolidated and interfingering lenses of sand, silt, clay, and gravel in the flood plains and channels of stream	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines.
	AND RECENT	Terrace deposits	0-100	Unconsolidated and interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above the flood plains of the principal streams.	Moderately permeable. Locally above the water table and not saturated. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

Table 3-1

(Page 2 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
PERMIAN	LOWER PERMIAN	Hennessey Group (includes Kingman Siltstone and Fairmont Shale)	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places water contains large amounts of sulfate.
		Garber Sandstone	500±	Deep-red clay to reddish-orange, massive and cross-bedded fine-grained sandstone interbedded and interfingered with red shale and siltstone	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

of a lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are often informally lumped together as the Garber-Wellington Formation. Together, they are about 900 feet thick at Tinker AFB. The interconnected, lenticular nature of sandstones within the sequence forms complex pathways for groundwater movement.

The surficial geology of the north section of the Base is dominated by the Garber Sandstone, which outcrops across a board area of Oklahoma County. Generally, the Garber outcrop is covered by a veneer of soil and/or alluvium up to 20 feet thick. To the south, the Garber Sandstone is overlain by outcropping strata of the Hennessey Group, including the Kingman Siltstone and the Fairmont Shale (Bingham and Moore, 1975). Drilling information obtained as a result of geotechnical investigations and monitoring well installation confirms the presence of these units.

Depositional Environment. The Permianage strata presently exposed at the surface in central Oklahoma were deposited along a low-lying north-south oriented coastline. Land features included meandering to braided sediment-loaded streams that flowed generally westward from highlands to the east (ancestral Ozarks). Sand dunes were common, as were cut-off stream segments that rapidly evaporated. The climate was arid and vegetation sparse. Off shore the sea was shallow and deepened gradually to the west. The shoreline's position varied over a wide range. Isolated evaporitic basins frequently formed as the shoreline shifted.

Across Oklahoma, this depositional environment resulted in an interfingering collage of fluviatile and wind-blown sands, clays, shallow marine shales, and evaporite deposits. The overloaded streams and evaporitic basins acted as sumps for heavy metals such as iron, chromium, lead, and barium. Oxidation of iron in the arid climate resulted in the reddish color of many of the sediments. Erosion and chemical breakdown of granitic rocks from the highlands resulted in extensive clay deposits. Evaporite minerals such as anhydrite ($CaSO_4$), barite ($BaSO_4$), and gypsum ($CaSO_4 \bullet 2H_2O$) are common.

Around Tinker AFB, the Hennessey Group represents deposition in a tidal flat environment cut by shallow, narrow channels. The Hennessey Group is comprised predominantly of red shales which contain thin beds of sandstone (less than 10 feet thick) and siltstone. In outcrop, "mudball" conglomerates, burrow surfaces, and dessication cracks are recognized. These units

outcrop over roughly the southern half of the Base, thickening to approximately 70 feet in the southwest from their erosional edge (zero thickness) across the central part of Tinker AFB.

In contrast, the Garber Sandstone and the Wellington Formation around Tinker AFB consist of an irregularly-interbedded system of lenticular sandstones, siltstones, and shales deposited either in meandering streams in the upper reaches of a delta or in a braided stream environment. Outcrop units north of Tinker AFB exhibit many small to medium channels with cut and fill geometries consistent with a stream setting. Sandstones are typically cross-bedded. Individual beds range in thickness from a few inches to approximately 50 feet and appear massive, but thicker units are often formed from a series of "stacked" thinner beds. Geophysical and lithologic well logs indicate that from 65 to 75 percent of the Garber Sandstone and the Wellington Formation are composed of sandstone at Tinker AFB. The percentage of sandstone in the section decreases to the north, south, and west of the Base. These sandstones are typically fine to very fine grained, friable, and poorly cemented. However, where sandstone is cemented by red muds or by secondary carbonate or iron cements, local thin "hard" intervals exist along disconformities at the base of sandstone beds. Shales are described as ranging from clayey to sandy, are generally discontinuous, and range in thickness from a few inches to approximately 40 feet.

Stratigraphic Correlation. Correlation of geologic units is difficult due to the discontinuous nature of the sandstone and shale beds. However, cross-sections (Figure 3-1) demonstrate that two stratigraphic intervals can be correlated over large sections of the Base in the conceptual model. These intervals are represented on geologic cross-sections A-A' and B-B' (Figures 3-2 and 3-3). Section A-A' is roughly a dip section and B-B' is approximately a strike section. The first correlatable interval is marked by the base of the Hennessey Group and the first sandstone at the top of the Garber Sandstone. This interval is mappable over the southern half of Tinker AFB. The second interval consists of a shale zone within the Garber Sandstone which, in places, is comprised of a single shale layer and, in other places, of multiple shale layers. This interval is more continuous than other shale intervals and in cross-sections appears mappable over a large part of the Base. It is extrapolated under the central portion of Tinker AFB where little well controls exists.

Structure. Tinker AFB lies within a tectonically stable area; no major near-surface faults or fracture zones have been mapped near the Base. Most of the consolidated rock units of the Oklahoma City area dip westward at a low angle. A regional dip of 0.0057 to 0.0076 ft/ft in

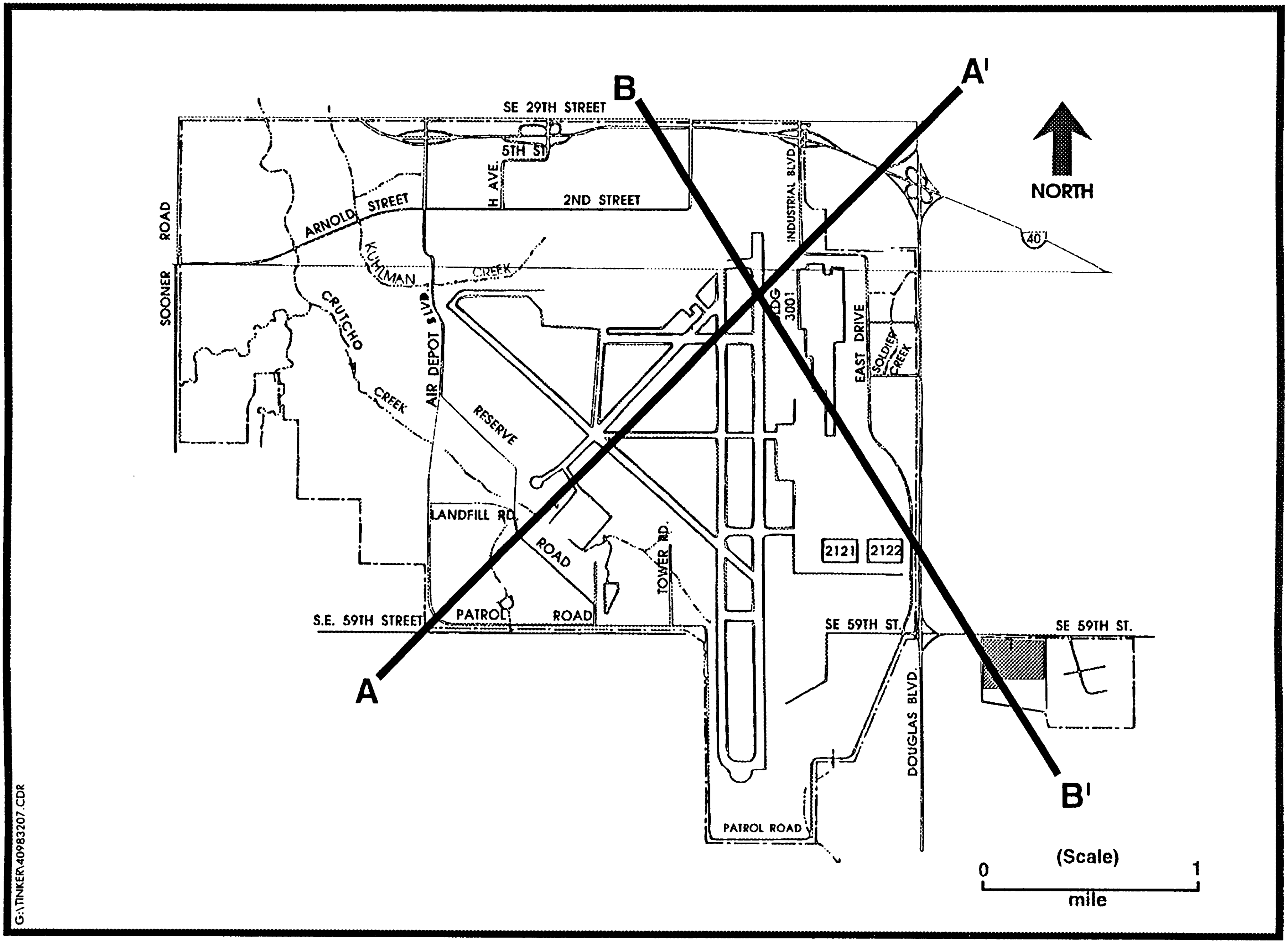

FIGURE 3-1 TINKER AFB GEOLOGIC CROSS SECTION LOCATION MAP

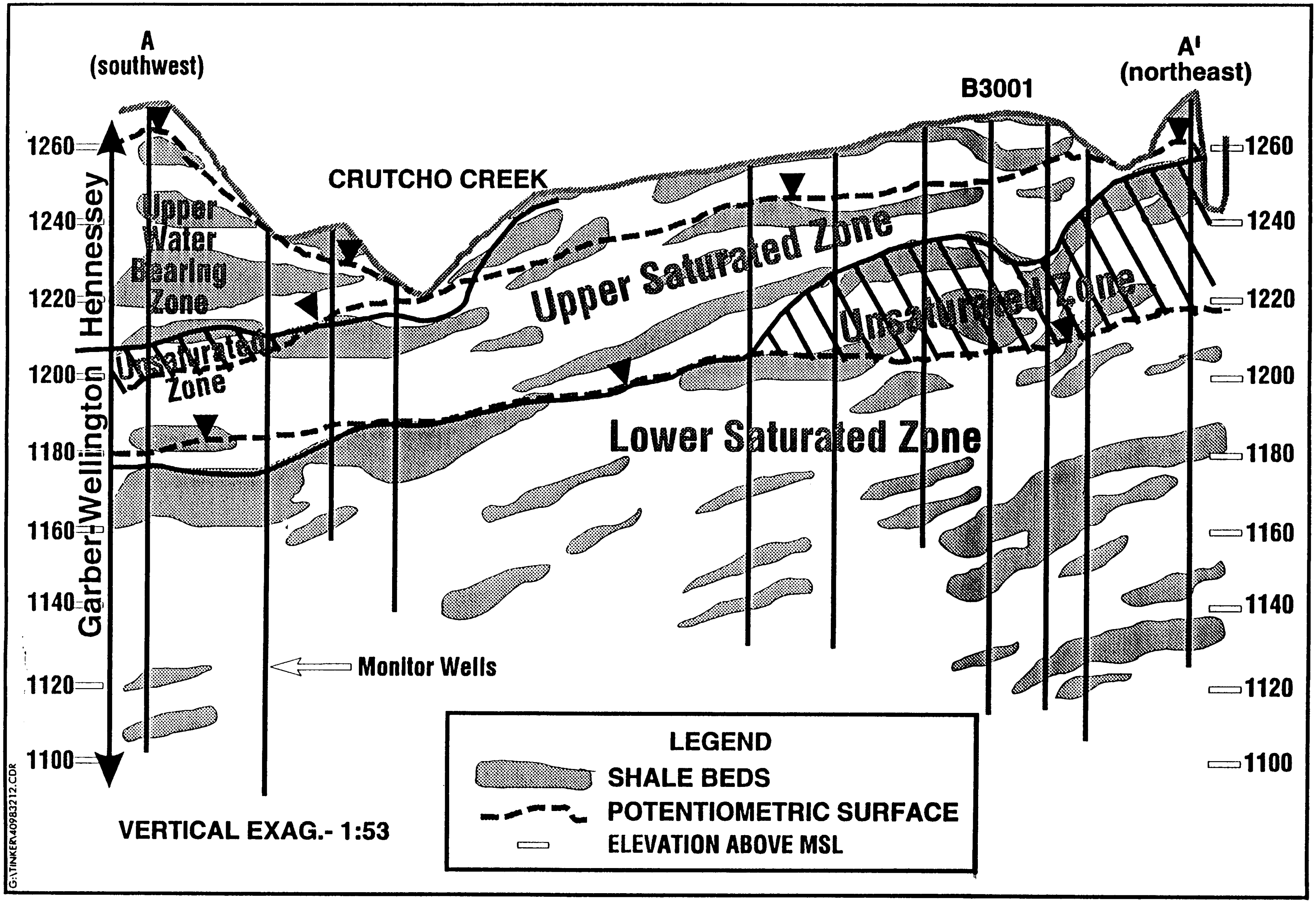

FIGURE 3-2 TINKER AFB GEOLOGIC CROSS SECTION A-A'

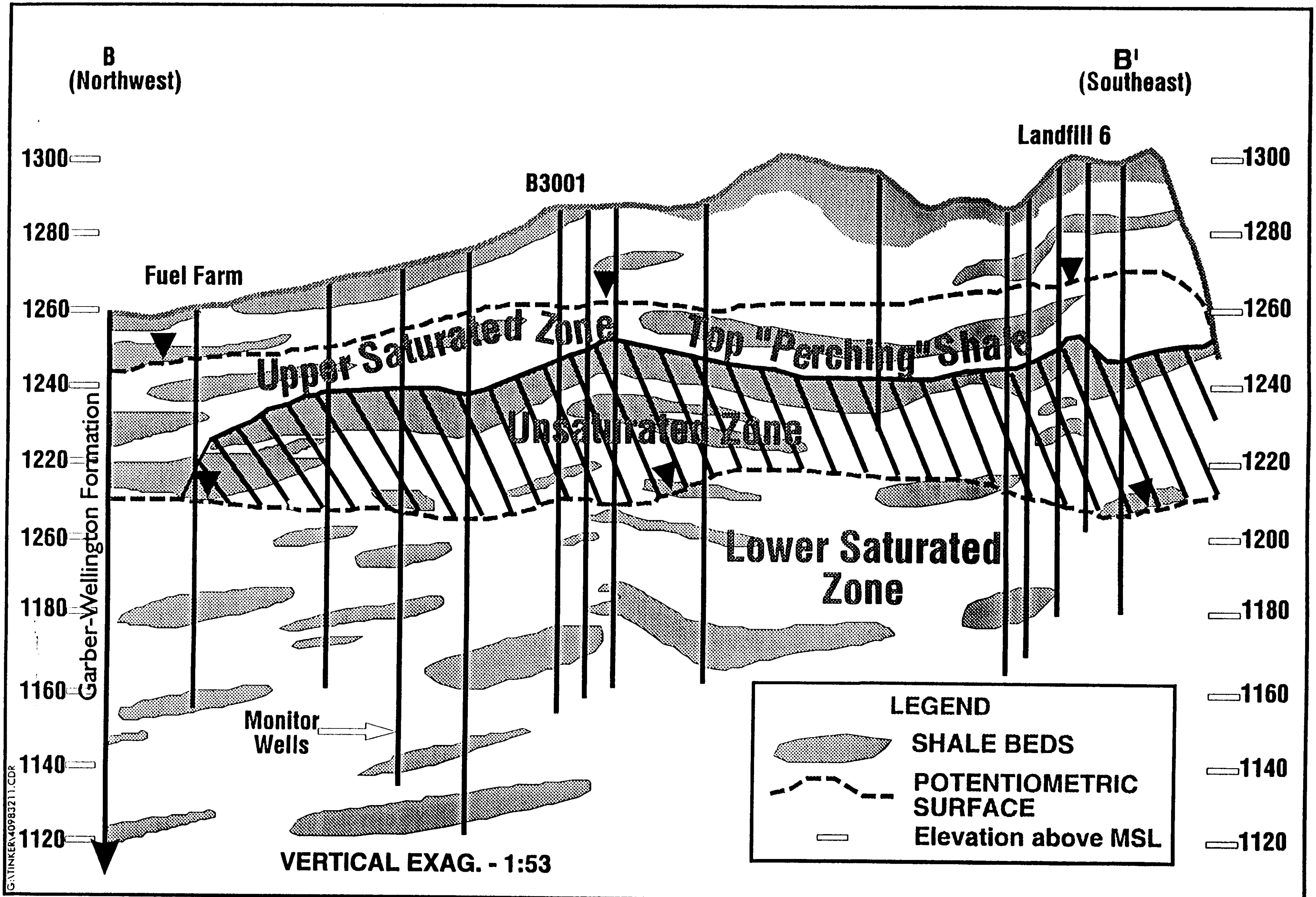

FIGURE 3-3 TINKER AFB GEOLOGIC CROSS SECTION B-B'

a generally westward direction is supported by stratigraphic correlation on geologic cross-sections at Tinker AFB. Bedrock units strike slightly west of north.

Although Tinker AFB lies in a tectonically stable area, regional dips are interrupted by buried structural features located west of the Base. A published east-to-west generalized geologic cross-section, which includes Tinker AFB, supports the existence of a northwest-trending structural trough or syncline located near the western margin of the base. The syncline is mapped adjacent to and just east of a faulted anticlinal structure located beneath the Oklahoma City Oil Field. The fault does not appear to offset Permian-age strata. There are indications that the syncline may act as a "sink" for some regional groundwater (southwest flow) at Tinker AFB before it continues to more distant discharge points.

3.2.2 Site Geology

Landfill 6 is located near the contact between the Hennessey Group and the Garber Sandstone of the Garber-Wellington Formation. Most of the landfill itself is excavated within the Fairmont Shale unit of the Hennessey Group. This shale unit is relatively thin and ranges in thickness from 5 to 28 feet. Below the Hennessey Group are discontinuous beds of the Garber-Wellington Formation. These beds consist of interbedded shales and fine-grained sandstones. The sandstones are dominant and range in thickness from 1 to 60 feet. Additional lenticular masses of shale are found within the underlying Garber Sandstone. North of the landfill, the Hennessey Group shales are absent.

3.3 Hydrology

3.3.1 Regional/Tinker AFB Hydrology

The most important source of potable groundwater in the Oklahoma City metropolitan area is the Central Oklahoma aquifer system. This aquifer extends under much of central Oklahoma and includes water in the Garber Sandstone and Wellington Formation, the overlying alluvium and terrace deposits, and the underlying Chase, Council Grove, and Admire Groups. The Garber Sandstone and the Wellington Formation portion of the Central Oklahoma aquifer system is commonly referred to as the "Garber-Wellington aquifer" and is considered to be a single aquifer because these units were deposited under similar conditions and because many of the best producing wells are completed in this zone. On a regional scale, the aquifer is confined above by the less permeable Hennessey Group and below by the Late Pennsylvanian Vanoss Group.

Tinker AFB lies within the limits of the Garber-Wellington Groundwater Basin. Currently, Tinker derives most of its water supply from this aquifer and supplements the supply by purchasing from the Oklahoma City Water Department. The nearby communities of Midwest City and Del City derive water supplies from both surface sources and wells tapping the aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by a municipal distribution system also depend on the Garber-Wellington aquifer. Communities presently depending upon surface supplies (such as Oklahoma City) also maintain a well system drilled into the Garber-Wellington as a standby source of water in the event of drought.

Recharge of the Garber-Wellington aquifer is accomplished principally by percolation of surface waters crossing the area of outcrop and by rainfall infiltration in this same area. Because most of Tinker AFB is located in an aquifer outcrop area, the Base is considered to be situated in a recharge zone.

According to Wood and Burton (1968) and Wickersham (1979), the quality of groundwater derived from the Garber-Wellington aquifer is generally good, although wide variations in the concentrations of some constituents are known to occur. Wells drilled to excessive depths may encounter a saline zone, generally greater than 900 feet below ground surface. Wells drilled to such depths or those accidentally encountering the saline zone are either grouted over the lowest screens or may be abandoned.

Tinker AFB presently obtains its water supplies from a distribution system comprised of 29 water wells constructed along the east and west Base boundaries and by purchase from the Oklahoma City Water Department. All Base wells are finished into the Garber-Wellington aquifer. Base wells range from 700 to 900 feet in finished depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones with a combined thickness from 103 to 184 feet (Wickersham, 1979).

Although the variability in the geology and the recharge system at Tinker AFB makes it difficult to predict local flow paths, Central Oklahoma aquifer water table data show that regional groundwater flow under Tinker varies from west-northwest to southwest, depending on location. This theory is supported by contoured potentiometric data from base monitoring wells which show groundwater movement in the upper and lower aquifer zones to generally follow regional dip. Measured normal to potentiometric contours, groundwater flow gradients

range from 0.0019 to 0.0057 ft/ft. However, because flow in the near-surface portions of the aquifer at Tinker AFB is strongly influenced by topography, local stream base-levels, complex subsurface geology, and location in a recharge area, both direction and magnitude of groundwater movement is highly variable. The interaction of these factors not only influences regional flow but gives rise to complicated local, often transient, flow patterns at individual sites.

As a result of ongoing environmental investigations and the approximately 450 groundwater monitoring wells installed on the Base during various investigations, a better understanding of the specific hydrological framework has emerged. The current conceptual model developed by Tinker AFB (Tinker, 1993), based on the increased understanding of the hydrological framework, has been revised from an earlier model adopted by the USACE. Previous studies reported that groundwater was divided into four water-bearing zones: the perched aquifer, the top of regional aquifer, the regional aquifer, and the producing zone. In the current model, two principal water table aquifer zones and a third less extensive zone have been identified. The third is limited to the southwest quadrant. The third aquifer zone consisted of saturated siltstone and thin sandstone beds in the Hennessey Shale and equates to the upper water bearing zone (UWBZ) described by the USACE (USACE, 1993b) at Landfills 1 through 4 (SWMUs 3 through 6). In addition, numerous shallow, thin saturated beds of siltstone and sandstone exist throughout the Base. These are of limited areal extent and are often perched.

In the current conceptual hydrologic model, a USZ and an LSZ are recognized in the interval from ground surface to approximately 200 feet. Below this is found the producing zone from which the Base draws much of its water supply Figure 3-4 shows the potentiometric surface for the USZ and Figure 3-5 shows the potentiometric surface for the LSZ. The USZ exists mainly under water table (unconfined) conditions, but may be partially confined locally. Conditions in the LSZ are difficult to determine due to screen placement and overly long sandpacks below the screen interval.

The USZ is found at a depth of 5 to 70 feet below ground surface and has a saturated thickness ranging from less than 1 foot at its eastern boundary to over 20 feet in places west of Building 3001 depending on topography. The USZ is erosionally truncated by Soldier Creek along the northeastern margin of Tinker AFB. This aquifer zone is considered to be a perched aquifer over the eastern one-third of Tinker AFB, where it is separated from the LSZ by an underlying confining shale layer and a vadose zone. The confining interval extends across the entire Base, but the vadose zone exists over the eastern one-third of this area. The

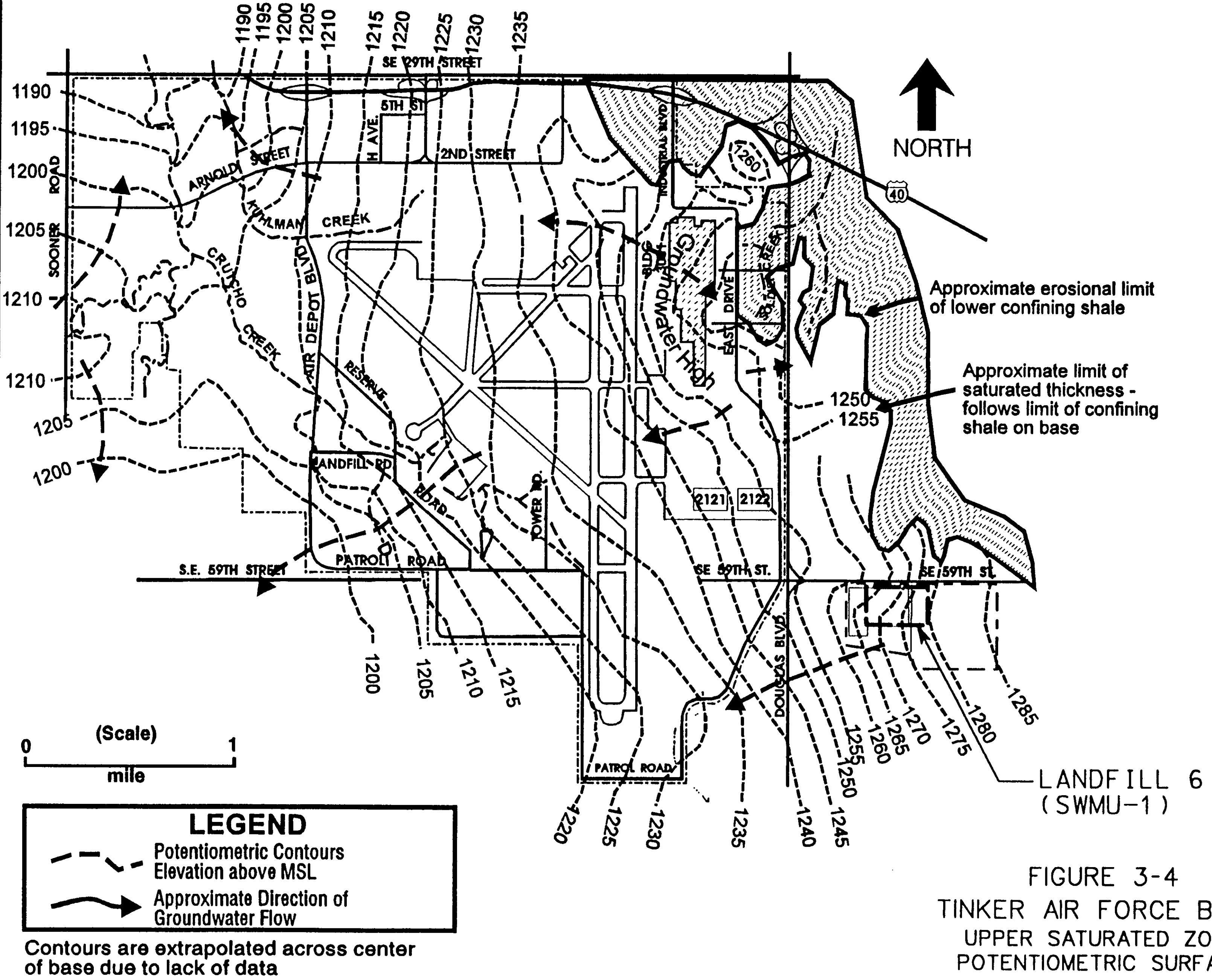

FIGURE 3-4
TINKER AIR FORCE BASE
UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 23MAR94	DATE LAST REV.:	DRAFT. CHCK. BY:	INITIATOR: C.WALLACE	DWG. NO.: 40983209C.
DRAWN BY: C.E.TUMLIN	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J.TAYLOR	PROJ. NO.: 409832

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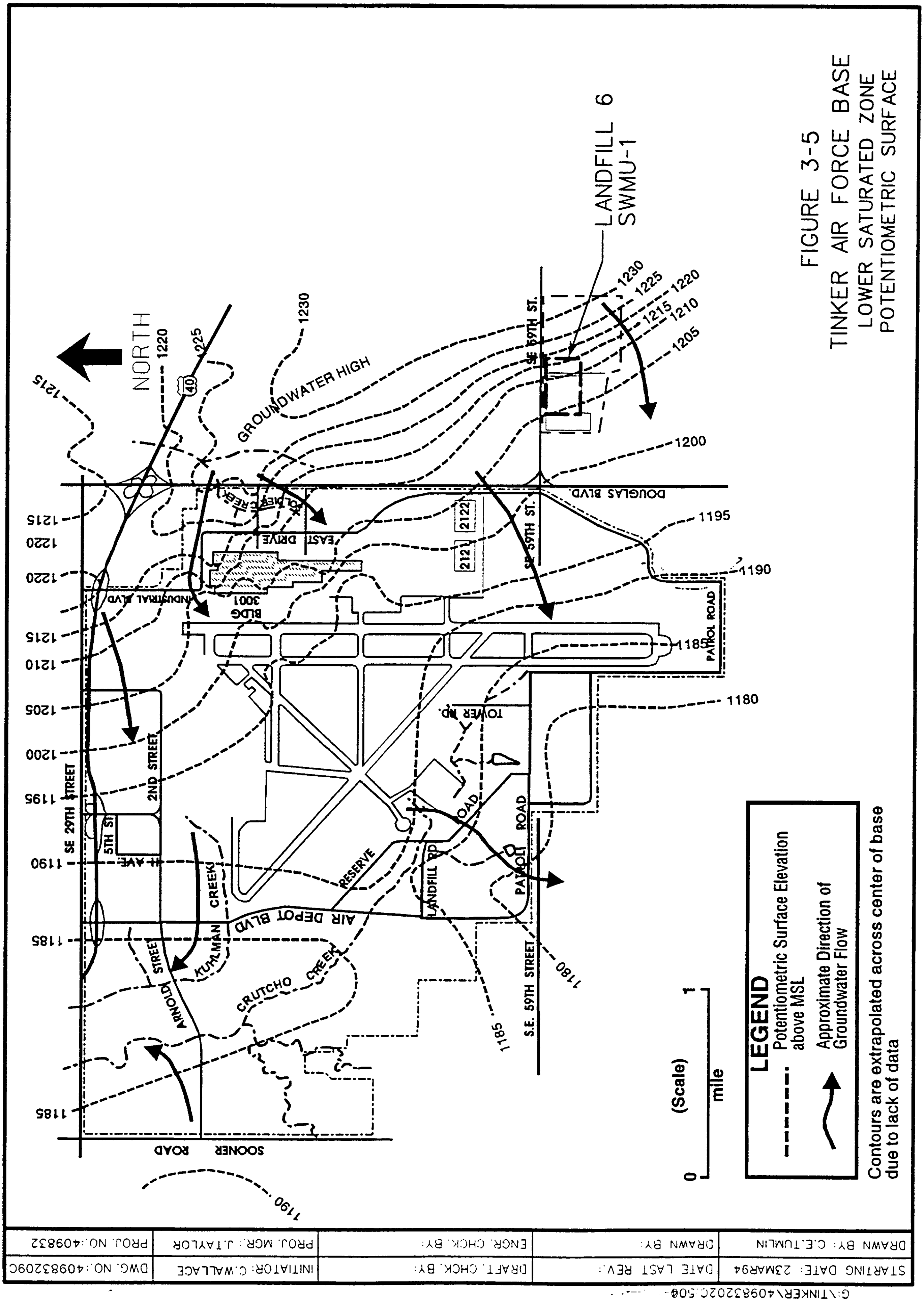


FIGURE 3-5
TINKER AIR FORCE BASE
LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE

available hydrogeologic data indicate that the vadose zone does not exist west of a north-south line located approximately 500 to 1,000 feet west of the main runway; consequently, the USZ is not perched west of this line. However, based on potentiometric head data from wells screened above and below the confining shale layer, the USZ remains a discrete aquifer zone distinct from the LSZ even over the western part of the Base. In areas where several shales interfinger to form the lower confining interval rather than a single shale bed, "gaps" may occur. In general, these "gaps" are not holes in the shale, but are places where multiple shales exist that are separated by slightly more permeable strata. Hydrologic data from monitoring wells indicate that these zones allow increased downward flow of groundwater above what normally leaks through the confining layer.

The LSZ down to a depth of approximately 200 feet appears to be hydraulically interconnected over most of Tinker. The 200-foot depth was chosen as the base for the current conceptual model since hydrologic data from a few deeper wells indicate that the producing zone below the LSZ may be hydrologically isolated from the shallower zones at LSZ includes the top of regional and regional zones referred to in USACE reports.

Due to variations in topography, the top of the lower zone is found at depths ranging from 50 to 100 feet below ground surface under the eastern parts of the Base and as shallow as 30 feet to the west. Differences in potentiometric head values found at successive depths are due to a vertical (downward) component of groundwater flow in addition to lateral flow and the presence or absence of shale layers which locally confine the aquifer system. The LSZ extends east of the Base (east of Soldier Creek) beyond the limits of the USZ where it becomes the first groundwater zone encountered in off-Base wells. Because of the regional dip of bedding, groundwater gradient, and topography, the LSZ just east of the Base is generally encountered at depths less than 20 feet.

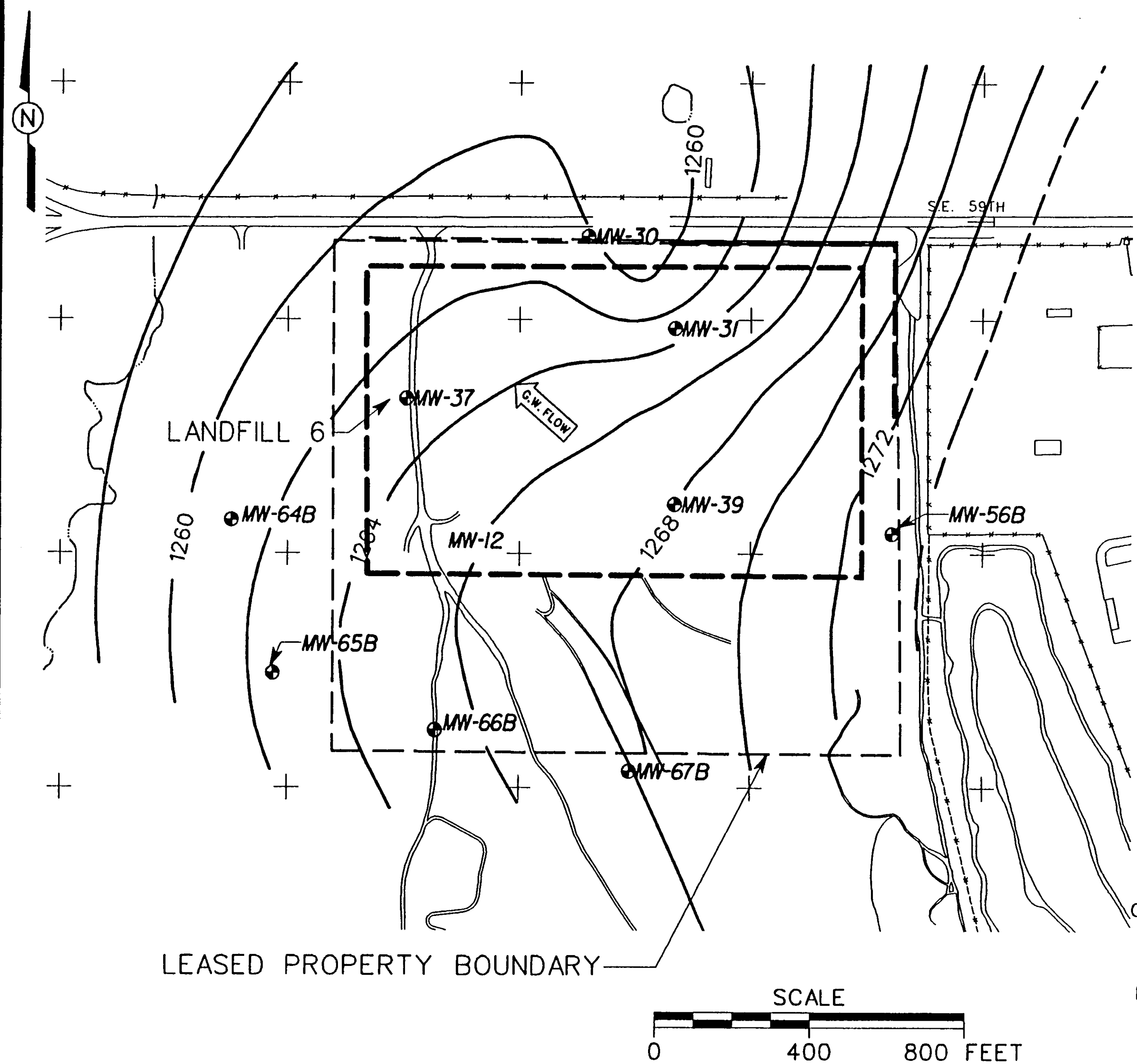
3.3.2 Site Hydrology

Landfill 6 is located within an outcrop of the Hennessey Group. Earlier reports indicated numerous bodies of perched groundwater being located between the landfill and the regional aquifer (Radian, 1985). A perched water table (USZ) was reported to exist at a depth of 20 feet below the surface. The existence of this high water table was responsible for flooding several trenches, now covered, in the eastern portion of the site. It was believed that the presence of one or more shale units underneath the site was responsible for the perched aquifer, as well as inducing a strong horizontal component of groundwater flow. Local stratigraphic variations within the USZ created hydraulic gradients varying from 0.0082 ft/ft across the landfill to 0.0047 ft/ft west of the landfill, flowing in the vicinity of the landfill, in a west-to-northwest direction. Average horizontal hydraulic conductivity, as determined by USACE tests, was 1.0 x 10^{-3} centimeters per second (cm/s). Given an estimated effective porosity of 20 percent, USACE (1993) reports the average groundwater velocity in this region to be approximately 47 feet per year.

Groundwater was encountered during the USACE RI at depths of 11 feet for the USZ, extending to approximately 48 feet below land surface. The LSZ was encountered at a depth of 68 feet below land surface. Potentiometric surface maps for Landfill 6 are provided as Figure 3-6 for the USZ, and Figure 3-7 for the LSZ.

3.4 Soils

Three major soil types have been mapped in the Tinker AFB area and are described in Table 3-2 (U.S. Department of Agriculture [USDA], 1969). The three soil types, the Darrell-Stephenville, Renfrow-Vernon-Bethany, and Dale-Canadian-Port, consist of sandy to fine sandy loam, silt loam, and clay loam, respectively. The Darrell-Stephenville and the Renfrow-Vernon-Bethany are primarily residual soils derived from the underlying shales of the Hennessey Group. The Dale-Canadian-Port association is predominantly a stream-deposited alluvial soil restricted to stream floodplains. The thickness of the soils ranges from 12 to 60 inches. Landfill 6 lies entirely within the Darrell-Stephenville soil association.



LEGEND:

MW-31 MONITORING WELL

DATA DATE: MARCH 1993

CI: 2 FEET

NOTE:

1. DATA EXTRAPOLATED FROM ADDITIONAL DATA POINTS OUTSIDE PICTURED AREA

FIGURE 3-6

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 6
UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 01/14/94	DATE LAST REV.: / /	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P. TERRY	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

9/22/94 P01
FILENAME:G:\TINKER\40983202.097

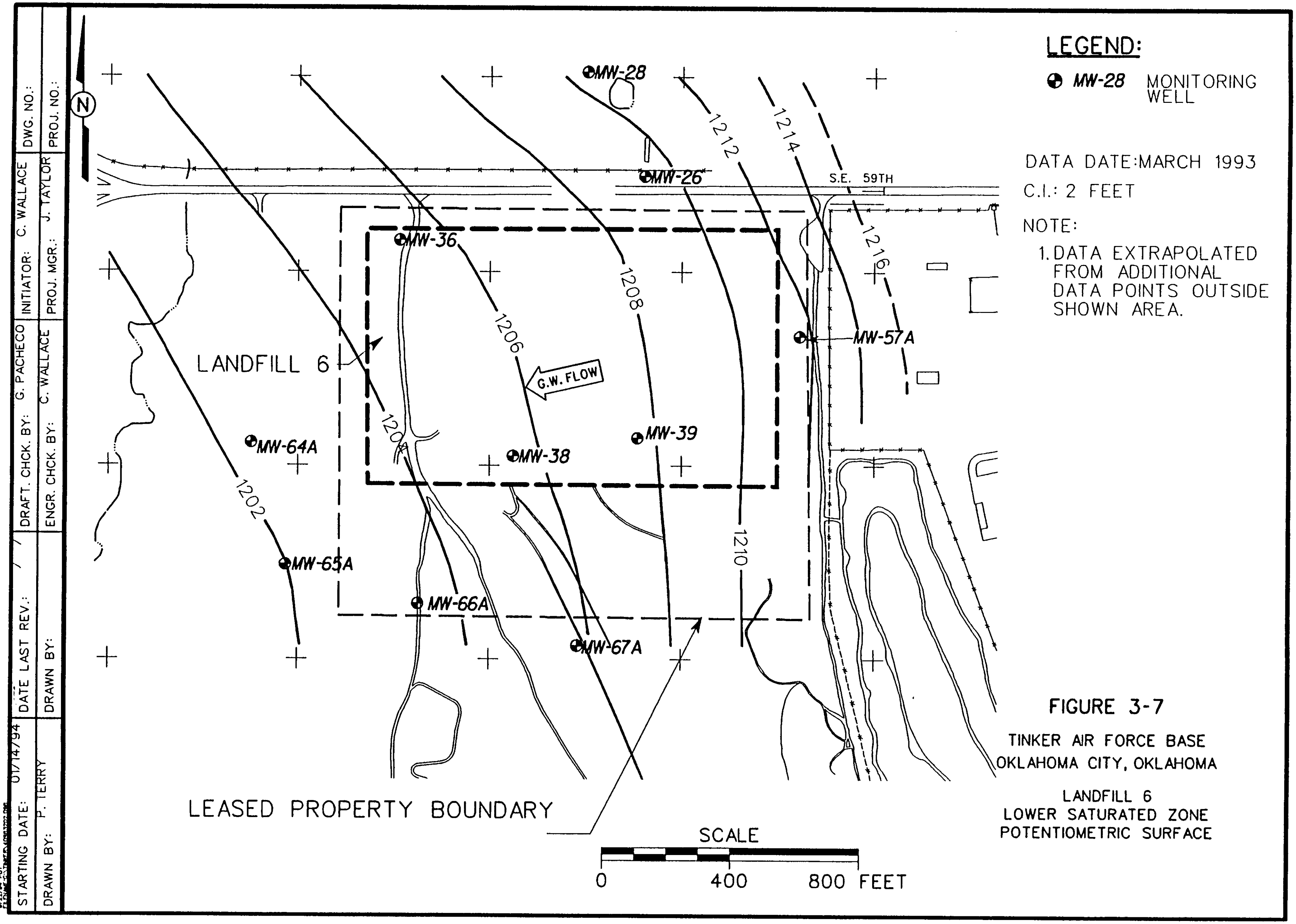


FIGURE 3-7

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 6
LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE

Table 3-2

Tinker AFB Soil Associations (Source: USDA, 1969)

Association	Description	Thickness (in.)	Unified Classification[a]	Permeability (in./hr)
Darrell-Stephenville: loamy soils of wooded uplands	Sandy loam Sandy clay loam Soft sandstone (Garber Sandstone)	12-54	SM,ML,SC	2.0-6.30
Renfrow-Vernon-Bethany: loamy and clayey soils on prairie uplands	Silt loam - clay Clay loam Shale (Fairmont Shale)	12-60	ML,CL,MH,CH	<0.60-0.20
Dale-Canadian-Port: loamy soil on low benches near large streams	Fine sandy loam Silty clay loam Loam Clay loam	12-60	SM,ML,CL	0.05-6.30

[a]Unified classifications defined in U.S. Bureau of Reclamation, 5005-86.

4.0 Source Characterization

Landfill 6 was used for the disposal of an estimated 500,000 yd^3 of sanitary and industrial refuse generated by Tinker AFB from 1970 to 1979 (Radian, 1985a). Sanitary wastes deposited in the landfill consisted of items such as paper, lumber, leaves, branches, food, and other household wastes. Industrial wastes included paint, insecticide, and solvent containers. Industrial waste sludges were also reported to have been disposed of at Landfill 6. The landfill is located approximately one-half mile east of the main Base on property leased by Tinker AFB from Oklahoma City.

Landfill 6 was constructed by excavating a series of parallel trenches. Waste was deposited within the trenched area and covered with compacted soil. The cover soil type varied from highly permeable sands to less permeable clays and sand/clay mixtures. After closure of Landfill 6 in 1979, the trenched areas were covered with an engineered compacted-clay cap to retard percolation of surface waters through the waste materials and revegetated with grass to control surface erosion (USACE, 1990).

During the course of the remedial investigations conducted by the USACE, 20 IRP soil borings were drilled within the landfill trenches. The borings were drilled with an auger to various depths, with samples of the waste in the trenches collected when encountered. The waste encountered was composited into one sample for analysis. Upon completion of the boring, the coordinates and ground elevations were surveyed for each boring. The landfill was found to cover approximately 25 acres. Geologic logs for the borings are contained in the USACE 1990 RI report. Table 4-1 contains the waste description and depth of occurrence for each boring (USACE, 1990). Waste materials were encountered in 19 of the 20 trench borings.

The solid waste samples were analyzed for metals, TOC, cyanide, pH, EC, volatile organics, SVOCs, and pesticides. VOCs, SVOCs, and cyanide were detected sporadically and with various concentrations throughout the landfill. Metals and TOC were also detected throughout the landfill with various concentrations.

Groundwater was encountered within the landfill trenches during the drilling of the soil borings. The trench water was sampled to determine the quality of the perched aquifer beneath Landfill 6. Cover soil material and perched groundwater within the landfill trenches was found to be contaminated through contact with the waste material disposed of in this

Table 4-1

Waste
SMWU-1, Landfill 6 Tinker AFB

Boring No.	Waste Description	Depth (feet)
L6-1	Paper and plastic products	4.0-22.0
L6-2	Paper and plastic products	7.0-13.0
L6-3	Aluminum cans, paper, and plastic products	6.0-25.0
L6-4	Rags, carpet, paper, and plastic products	5.0-20.0
L6-5	Wire, cloth, aluminum cans, paper, and plastic products	5.0-17.0
L6-6	Wire, paper, and plastic products	7.0-27.7
L6-7	Waste paper, plastic, wire	1.5-16.5
L6-8	Rags, scrap metal, plastic hose, paper, and plastic products	5.0-27.5
L6-10	Scrap metal, wire fencing, rags, paper, and plastic products	2.0-10.5
L6-11	Trash mixed with clay and organic material	5.0-15.0
L6-12	Paper and plastic products	8.0-24.0
L6-13	Paper, plastic, rags, wood chips, carpet, wire	12.0-27.0
L6-14	Wood shavings, paper, rags, plastic scrap metal	12.0-35.0
L6-15	Asphalt, cement, wood scraps, paper	7.0-16.0
L6-16	Sawdust, wood shavings, paper, wire, aluminum scraps	13.0-31.0
L6-17	Burned trash, paper, plastic, wire, rags, scrap metal	7.0-36.0
L6-18	Paper and plastic products	12.5-31.5
L6-19	Paper, plastic, scrap metal, wire, aluminum cans	12.0-30.0
L6-21	Waste not found	--
L6-22	Paper, wood, plastic	8.0-25.0

Reference: U.S. Army Corps of Engineers (USACE), RI Report, Landfill 6, December 1990.

landfill. The nature and extent of soil and groundwater contamination is discussed in detail in Chapter 5.0, Contaminant Characterization.

5.0 Contaminant Characterization

Through several phases of investigation, soils, groundwater, and stream sediments have been randomly sampled for contaminants potentially introduced into the environment as a result of past waste disposal practices at Landfill 6. Analytical results of samples taken in and around Landfill 6 indicate concentrations of metals above background levels, as well as VOCs and SVOCs. Contaminants appear to be sporadic throughout the site, with no continuous concentrations in any one area.

Soils. During RI activities performed by the USACE under the IRP (USACE, 1990), samples were obtained from 20 soil borings drilled into the landfill trenches at Landfill 6. Although the samples contained waste products representative of the disposed waste material, they were also samples of the soil cover material used daily to cover and compact the deposited wastes. The soil samples were analyzed for metals, TOC, cyanide, pH, EC, VOCs, SVOCs, and pesticides. VOCs, SVOCs, and cyanide were detected sporadically and with varying concentrations throughout the landfill. Metals and TOC were also detected throughout the landfill with varying concentrations. A summary of organic and inorganic data from the trench soil samples is provided in Table 5-1.

Background soil concentrations for trace metals were determined based on a study performed by the USGS (1991). The study area was confined to approximately four counties in central Oklahoma. Tinker AFB lies at the approximate center of this area. A total of 293 B-horizon soil samples were collected throughout this area. Soil samples were collected at the top of the B-horizon, which was usually 20 to 30 centimeters below the surface but ranged from 3 to 50 centimeters below the surface. For site-specific analytes for which the USGS offered no background value, the analyte was compared to an applicable action level. The background concentrations are presented in Table 5-2.

The use of B-horizon soil as selected by the USGS for metals background concentrations in soil is conservative in that the soil sampled does not reflect all possible anthropogenic influences. Most of the samples were obtained from hill crests and well drained areas in pasture and forested land, well away from roadways to minimize contamination from vehicular emissions (i.e., nearly "pristine" areas). Trace metal inputs to the study site soils on Base, however, will come from anthropogenic sources outside of the study area, in addition to

Table 5-1

Summary of Analytical Results, Trench Soil Samples, SWMU-1, Landfill 6, Tinker AFB

(Page 1 of 4)

Compound	L6-1	L6-2	L6-3	L6-4	L6-5	L6-6	L6-7	L6-8	L6-10
Organics (µg/kg)									
2-Butanone	4200	31	<1760[a]	6300	460	2800	1500	350	53
Ethyl benzene	24000	<6	<880[a]	<1095[a] J	<6	<905[a]	1500	<7	<6
Total xylenes	170000	7	500	2400	500	<905[a]	7100	130	6 J
Naphthalene	<12000[a]	31000	2300 J	<18000[a]	4200 J	<29000[a]	<12000[a]	<8900[a]	<390
Bis(2-ethylhexyl)phthalate	2200 J	3500	2300 J	75000	6600	2800 J	12000 J	7900 J	110 J
4-Methyl-2-pentanone	<3080[a]	12 J	<1760[a]	2400	2500	<1810[a]	<12	<13	22
Toluene	<1540[a]	<6	230 J	2600	310	1400	9100	300	<6
Methylene chloride	<1540[a]	6 J	<880[a]	<2190[a]	19	<1810[a]	<12	26	7
Acetone	<3080[a]	<12	<1760[a]	<2190[a]	1400	<1810[a]	36000	420	570
2-Hexanone	<3080[a]	<12	<1760[a]	<2190[a]	450	<1810[a]	160	24	12 J
Trichloroethene	<1540[a]	<6	<880[a]	<1095[a]	6 J	<905[a]	23	<7	<6
Tetrachloroethene	<1540[a]	<6	<880[a]	1095 J	9	<905[a]	280	65	<6
Chlorobenzene	<1540[a]	<6	<880[a]	<1095[a]	<6	<905[a]	130	<7	<6
Inorganics (mg/kg)									
Silver	0.7	0.7	1.1	11	5.5	1.1	0.65	2.4	0.9
Arsenic	1.4	1.7	5.1	2.2	2.6	4.2	1.6	2.4	1.5
Barium	370	170	100	260	290	91	130	830	260

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Table 5-1

(Page 2 of 4)

Compound	L6-1	L6-2	L6-3	L6-4	L6-5	L6-6	L6-7	L6-8	L6-10
Cadmium	2.3	2.9	8.3	5.9	32	6.1	6.7	5.1	1.3
Chromium	140	13	13	19	40	25	14	26	67
Mercury	0.17	<0.1	0.46	0.17	0.11	<0.1	<0.1	0.23	<0.1
Nickel	28	16	19	46	83	37	19	27	230
Lead	570	14	11	45	48	50	18	26	35
Selenium	0.9	<0.1	<0.1	0.6	0.19	0.2	<0.1	0.3	0.4
Cyanide	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Zinc	91	63	130	300	200	430	240	720	30
TOC	5900	4000	5600	14000	5100	2800	1700	6600	2800
pH	6.99	6.82	5.33	6.86	7.02	6.02	6.09	6.66	7.78
Conductivity	0.69	0.68	2.8	2.8	1.3	2.8	19.29	1.6	0.79

Table 5-1

(Page 3 of 4)

Compound	L6-11	L6-12	L6-13	L6-14	L6-15	L6-16	L6-17	L6-18	L6-19	L6-22
Organics (µg/kg)										
2-Butanone	<12	320	<15	80	<12	<21	<14	1400	480	1500
Ethyl benzene	<6	11	<7	<6	<6	60	27	17	<7	98
Total xylenes	<6	56	310	31	<6	540	46	<7	41	3000
Naphthalene	<410	<2200[a]	<15000[a]	4300 J	<810	<8500[a]	<14000[a]	<2400[a]	<14000[a]	13000 J
Bis(2-ethylhexyl)phthalate	150 J	40000[a]	<15000[a]	4300 J	2200	8500 J	<14000[a]	2400 J	<14000[a]	17000
4-Methyl-2-pentanone	<12	27	230	2700	<12	<21	<14	<14	<14	34
Toluene	<6	56	2400	44	<6	16	<7	44	180	2400
Methylene chloride	6 J	<6	<7	<6	<6	24	<7	8	53	71
Acetone	<12	820	890	170	<12	<21	<14	2000	520	<2900
2-Hexanone	<12	62	35	17	<12	<21	<14	110	<56	38
Trichloroethene	<6	<6	14	<6	<6	<11	<7	<7	31	160
Tetrachloroethene	<6	<6	10	<6	<6	<11	<7	<7	83	4800
Chlorobenzene	<6	<6	<7	15	<6	57	340	<7	<7	<7
Inorganics (mg/kg)										
Silver	1.5	1.8	<0.5	5.7	3.4	4.2	11	1.4	1.4	2.1
Arsenic	1.8	<1.0	1.1	1	<1.0	1.6	2.2	<1.0	<1.0	<1.0
Barium	1000	610	290	140	370	160	150	220	77	82
Cadmium	2.2	9.4	0.59	12	3.7	32	34	2.8	5.1	15
Chromium	35	60	22	80	47	230	96	46	20	120

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Table 5-1

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Compound	L6-11	L6-12	L6-13	L6-14	L6-15	L6-16	L6-17	L6-18	L6-19	L6-22
Mercury	<0.1	<0.1	0.15	0.5	<0.1	0.89	0.42	<0.1	0.30	0.42
Nickel	240	41	13	66	140	130	120	34	24	130
Lead	82	48	10	270	48	290	120	68	24	59
Selenium	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Zinc	30	120	92	450	39	280	750	240	270	430
Cyanide	<0.2	0.5	<0.2	0.62	<0.2	4.91	1.9	0.49	0.28	1.3
TOC	6200	9600	1500	14000	6400	11000	26000	4700	2900	30000
pH	8.57	7.14	7.45	6.66	7.74	6.89	7.22	7.34	7.05	5.72
Conductivity	5.1	0.84	1.0	1.7	0.67	2.7	1.4	1.3	1.4	1.4

[a]High detection limits are due to increased quantitation range necessary to identify another compound present in the sample.
J - Estimated value

Table 5-2

Background Concentrations of Trace Metals in Surface Soils[a] SWMU-1, Landfill 6, Tinker AFB

(Page 1 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Concentration in %			
Aluminum	0.005	0.38	8.9
Cadmium	0.005	0.01	9.4
Iron	0.005	0.18	5.8
Magnesium	0.005	0.02	5.3
Phosphorous	0.005	0.06	0.019
Potassium	0.05	0.1	2.4
Sodium	0.005	0.02	0.99
Titanium	0.005	0.04	0.42
Concentrations in ppm			
Arsenic	0.1	0.6	21
Barium	1	47	6400
Beryllium	1	<1	3
Bismuth	10	<DL[b]	<DL
Cadmium	2	<DL	<DL
Cerium	4	14	110
Chromium	1	5	110
Cobalt	1	<1	27
Copper	1	<1	59
Europium	2	---[c]	---
Gallium	4	<4	23
Gold	8	<DL	<DL
Holmium	4	<DL	<DL
Lanthanum	2	7	51
Lead	4	<4	27
Lithium	2	5	100

Table 5-2

(Page 2 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Manganese	10	24	3400
Molybdenum	2	<DL	<DL
Neodymium	4	6	47
Nickel	2	<2	61
Niobium	4	<4	16
Scandium	2	<2	15
Selenium	0.1	<0.1	1.2
Silver	2	<DL	<DL
Strontium	2	13	300
Tantalum	40	<DL	<DL
Thorium	1	<1.40	15.00
Tin	10	<DL	<DL
Uranium	0.1	0.650	6.400
Vanadium	2	5	220
Ytterbium	1	<1	3
Yttrium	2	3	43
Zinc	2	3	79

[a]All B-horizon soil samples (293) from USGS, 1991.
[b]All concentrations below the lower limits of determination.
[c]Insufficient or no data.

those sources related to disposal activities or operations within the confines of the study site. However, responsibility may be taken for more trace metal impacts than are actually attributable to a given site.

An additional level of conservatism was added in the manner in which the site-specific metals concentrations were compared to the background levels. Typically, the environmental concentrations of trace metals at study sites are represented by the arithmetic upper 95th confidence interval on the mean of a normal distribution. This upper 95th confidence interval value is then compared to the background values. The intent of this typical approach is to estimate a Reasonable Maximum Exposure case (i.e., well above the average case) that is still within the range of possible exposures.

To expedite this comparison and establish greater conservatism, the maximum concentration found at the site of concern, rather than the upper 95th confidence interval value, was compared to the USGS background values. If the environmental concentration of a particular analyte was below or within the minimum-maximum range of the USGS background concentrations, that analyte was considered to be naturally occurring and of no further concern to this investigation. Given the conservative approach of the comparisons, site-specific metals concentrations would have to significantly exceed the USGS background levels and be attributable to operations at the site before they would be considered a contaminant of concern.

Groundwater. Groundwater beneath Landfill 6 has been investigated during several investigations through the installation and sampling of several groundwater monitoring wells located throughout the site. A total of 18 monitoring wells have been installed to monitor the USZ (perched) groundwater aquifer. The saturated zone beneath the USZ, identified as the LSZ, has been investigated through the installation and sampling of 14 monitoring wells.

From 1986 through 1987, groundwater samples from available wells were analyzed for total and dissolved metals, TOC, oil and grease, chloride, sulfate, cyanide, pH, EC, VOCs, SVOCs, and pesticides. Sampling of all available monitoring wells was performed again in August through October 1988, and then again in September 1989. These samples were analyzed for total metals, TOC, chloride, sulfate, cyanide, pH, EC, VOCs, and SVOCs.

As a result of the 1991 focused RI performed by CDM (1992), six newly installed and six existing wells were sampled for chloride, sulfate, and TDS in August 1991 and again in April

1992. Additional sampling of select groundwater monitoring wells was performed in October and November 1991 by CDM as a result of a separate groundwater monitoring program for Tinker AFB. Sampling of all wells was performed in 1992 (Weston, 1993) and again in 1994 (IT Corporation, 1994, in progress) for the Long-Term Monitoring of Groundwater Quality Program.

An analytical summary of trench water samples is presented in Table 5-3. Table 5-4 provides a summary of 1986 to 1994 analytical results for monitoring wells installed within the USZ aquifer. Table 5-5 summarizes analytical results from 1986 to 1994 sampling of monitoring wells installed within the LSZ aquifer. Table 5-6 presents the results of the ion and TDS sampling performed in 1991 and 1992 on select Landfill 6 monitoring wells.

Sediments. Stream sediment from a tributary to Stanley Draper Lake was sampled in 1986 as a part of the RI activities conducted by the USACE. Six samples were taken from the stream bottom along the eastern and southern sections of the stream to investigate any contamination of the creeks near Landfill 6. Sediment samples were analyzed for total metals, TOC, cyanide, pH, EC, VOCs, SVOCs, and pesticides. A summary of the chemical analysis of these samples is presented in Table 5-7 (USACE, 1993).

5.1 Constituents of Potential Concern

Analytical results from soil, groundwater, and sediment samples from the Landfill 6 site are available from past IRP investigation activities. Evaluation of these analytical results for the specific purpose of identifying constituents of potential concern with respect to both human health and ecological impacts has not been performed. An interpretation has been made comparing Landfill 6 analytical results to elemental background concentrations in soils and, in the case of synthetic organic compounds in groundwater, to appropriate action levels. Groundwater results were compared to maximum contaminant levels (MCL). If an MCL was not available for a particular constituent, a comparison to the SWMU corrective action level (CAL) was made. The following sections summarize these interpretations.

5.2 Soil Characterization

Concentrations of most of the metals in the trench soil samples exceeded the background levels. The metals consisted of silver, barium, cadmium, chromium, nickel, lead, and zinc. Metals detected with concentrations significantly above the background values included barium, cadmium, lead, and zinc. Barium was detected at 150,000 milligrams per kilogram (mg/kg) in one sample and had an average concentration of 8,181 mg/kg. The Oklahoma

Table 5-3

Summary of Analytical Results, Trench Water
SWMU-1, Landfill 6, Tinker AFB

(Page 1 of 2)

Compound	L6-3	L6-5	L6-11	L6-13	L6-17
Metals (µg/L)					
Silver	<10	<10	<10	<10	40
Arsenic	20	28	3.3	10	9.2
Barium	4800	8700	<500	3100	5400
Cadmium	10	7.5	7.5	7.5	480
Chromium	15	<10	<10	18	610
Lead	93	68	75	53	1100
Mercury	<0.4	<0.4	<0.4	<0.4	3.8
Nickel	130	510	220	450	1800
Zinc	470	120	73	1000	66000
Organics (µg/L)					
Methylene chloride	180	910	6	<100[a]	350
Acetone	790	<10	<10	<200[a]	4800
1,1-Dichloroethane	37	<5	<5	<100[a]	<250[a]
Trans-1,2-dichloroethene	8	<5	<5	<100[a]	165J
2-Butanone	2200	100	<10	<200[a]	6600
1,2-Dichloropropane	21	<5	<5	<100[a]	<250[a]
Trichloroethene	13	<5	<5	<100[a]	<250[a]

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Table 5-3

(Page 2 of 2)

Compound	L6-3	L6-5	L6-11	L6-13	L6-17
TOC/TOL	48	160	20	210	5600
Oil/Grease				-	1.6
Chloride					590
Sulfate					220
Cyanide	<0.2	<0.2	<0.2	<0.2	<0.2
pH	6.86	6.8	7.11	6.68	5.57
Conductivity	2.58	4.36	1.87	2.79	18.7
2-Hexanone	2600	<10	<10	<200[a]	4400
4-Methyl-2-pentanone	83	<10	12	<200[a]	200J
Toluene	43	20	<5	170	2600
Total Xylenes	24	<5	<5	<35[a] J	760
Phenol	<100	110	<20	500[a] J	<2000[a]
2-Methylphenol	270	<100	<20	<500[a]	<2000[a]
4-Methylphenol	<100	340	<20	1700	2400
Benzoic Acid	<500	<500	<100	<2500	1211J
n-Nitrosodipropylamine	<100	190	<20	<500[a]	<2000[a]

J - Estimated value.
[a]High detection limit is due to increased quantitation range necessary to quantify another compound present in the sample.

Table 5-4

Summary of 1986 through 1989, 1991, 1992, 1994 Analytical Results Upper Saturated Zone Monitoring Wells, (µg/L) SWMU-1, Landfill 6, Tinker AFB

(Page 1 of 14)

	MW-12						MW-30					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	20.0	42.0	43.0	26.0	22.0	19.3	51	72	76	b	28.5	40.2
Barium	3200.0	11000.0	5400.0	5010.0	2630.0	3170	4900	12000	10000	b	12100	13400
Cadmium	5.0	9.0	13.0	--	--	--	20	--	18	b	--	--
Chromium	--	10.0	9.8	--	--	--	50	5.5	9	b	--	--
Mercury	--	0.1	--	--	--	--	--	--	--	b	--	--
Lead	73.0	31.0	20.0	1.7B	-	--	88	22	28	b	--	5.1
Nickel	200.0	--	--	35.1B	--	--	660	--	--	b	266	238
Selenium	--	--	--	--	--	--	--	--	0.6	b	--	--
Silver	--	--	--	--	--	--	13	--	--	b	--	--
Zinc	111.5	24.0	87.0	--	--	c	180	120	140	b	--	c
Organics												
1,1-Dichloroethane	21.0	--	--	--	41.0E	--	--	6.0	--	b	--	--
1,2-Dichloroethene	--	--	--	--	--	--	--	--	--	b	--	--
1,2,3-Trichlorobenzene	--	--	--	--	--	--	--	--	--	b	--	--
1,2,4-Trichlorobenzene	--	--	--	--	--	--	--	--	--	b	--	--
1,2,4-Trimethylbenzene	--	--	--	--	0.7	--	--	--	--	b	0.7	--
1,2-Dichlorobenzene	--	--	--	--	--	--	--	--	--	b	--	--
1,2-Dichloroethane	--	--	--	--	--	--	--	--	--	b	--	--
Cis-1,2-dichloroethene	--	--	--	--	--	--	--	--	--	b	--	--
Trans-1,2-dichloroethene	--	--	--	--	--	--	--	--	--	b	--	--
1,2-Dichloropropane	--	--	--	--	1.0	--	--	--	--	b	--	--

Table 5-4

	MW-12						MW-30					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Organics (Continued)												
1,3,5-Trimethylbenzene	--	--	--	--	0.5	--	--	--	--	b	--	--
1,3-Dichlorobenzene	--	--	--	--	--	--	--	--	--	b	--	--
1,4-Dichlorobenzene	--	14.0	7.0J	--	3.0	3.0	10.0J	20.0	12.0	b	12.0	19.0
2,2-Dichloropropane	--	--	--	--	--	--	--	--	--	b	--	--
2,4-Dimethylphenol	--	--	--	--	--	--	--	--	--	b	--	--
Acetone	1300.0	2500.0E	--	--	--	--	--	--	--	b	--	--
Benzene	7.0	--	--	--	12.0	--	9.0	--	12.0	b	2.0	--
Bis(2-chloroethyl)ether	--	--	--	--	--	--	--	--	--	b	--	--
Bis(2-ethylhexyl)phthalate	230.0	--	3.0BJ	--	--	3.0J	10.0J	--	--	b	--	--
Chlorobenzene	--	--	--	--	5.0	--	--	--	--	b	0.7	--
Chloroethane	--	--	--	--	10.0	--	--	--	--	b	1.0	--
Diethylphthalate	100.0J	120.0	99.0	--	8.0J	6.0J	12.0	13.0	30.0	b	34.0	39.0
Dimethylphthalate	--	--	--	--	17.0	19.0	--	--	--	b	--	--
Dichlorodifluoromethane	--	--	--	--	66.0E	--	--	--	--	b	--	--
Di-n-octylphthalate	--	8.0J	2.0BJ	--	--	--	10.0J	--	1.0J	b	--	--
Ethyl benzene	5.0J	45.0J	--	--	2.0	--	14.0	29.0	29.0	b	5.0	--
Isopropoylbenzene	--	--	--	--	0.5	--	--	--	--	b	0.6	--
p-Isopropyltoluene	--	--	--	--	--	--	--	--	--	b	--	--
Methylene chloride	--	66.0	6.0	--	6.0	--	5.0J	4.0J	9.0	b	0.9	--
Naphthalene	--	--	--	--	--	--	--	--	--	b	7.0J	5.0J
Tetrachloroethene	--	--	--	--	--	--	--	--	--	b	--	--
Toluene	47.0	130.0	12.0	--	10.0	--	16.0	6.0	12.0	b	--	--
Trichloroethene	8.0	--	--	--	1.0	--	--	--	--	b	--	--
Vinyl chloride	--	--	--	--	63.0E	--	--	--	--	b	--	--
Xylene (total)	30.0	27.0J	9.0	--	37.0	--	46.0	9.0	88.0	b	8.8	--

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Table 5-4

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	MW-31						MW-37					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	1.4	--	--	2.1B	2.0	5.2	17	13	24	21.4	23.0	27.0
Barium	990	2900	2900	3260	3870	3960	10000	18000	26000	18600	19900	14100
Cadmium	7.5	--	--	--	--	--	5	--	8.5	--	--	--
Chromium	--	--	--	--	--	--	15	10	19	--	--	--
Mercury	0.43	0.35	--	--	--	--	--	--	--	--	--	--
Lead	20	11	--	1.7B	--	--	50	18	24	1.3B	--	--
Nickel	200	--	--	145	169	139	1100	--	--	961	620	220
Selenium	--	--	0.9	--	--	--	0.5	0.8	--	--	--	--
Silver	--	--	--	--	--	--	--	--	--	--	--	--
Zinc	18	14	--	--	--	c	88	140	100	26.4	--	c
Organics												
1,1-Dichloroethane	--	15.0	16.0	11.0	89.0	6.0	25.0	28.0	4.0J	17.0	31.0E	17.0
1,2-Dichloroethene	--	--	--	6.0	--	5.0	--	--	--	--	--	3.0
1,2,3-Trichlorobenzene	--	--	--	--	0.7	--	--	--	--	--	--	--
1,2,4-Trichlorobenzene	--	--	--	--	0.5	--	--	--	--	--	0.5	--
1,2,4-Trimethylbenzene	--	--	--	--	--	--	--	--	--	--	1.0	--
1,2-Dichlorobenzene	--	--	--	--	8.0	9.0J	--	--	--	30.0	32.0	18.0
1,2-Dichloroethane	--	--	--	--	7.0	--	--	--	--	--	--	--
Cis-1,2-dichloroethene	--	--	--	--	6.0	4.0	--	--	--	--	2.0	2.0
Trans-1,2-dichloroethene	--	--	--	--	--	--	--	--	--	--	--	--
1,2-Dichloropropane	--	--	--	--	--	1.0	--	--	--	--	2.0	--
1,3,5-Trimethylbenzene	--	--	--	--	--	--	--	--	--	--	1.0	1.0
1,3-Dichlorobenzene	--	--	--	--	--	--	--	--	--	--	3.0	1.0
1,4-Dichlorobenzene	--	7.0J	5.0J	--	13.0	14.0	--	50.0	61.0	28.0	37.0	20.0
2,2-Dichloropropane	--	--	--	--	0.8	--	--	--	--	--	--	--
2,4-Dimethylphenol	--	--	--	--	--	--	--	--	--	--	28.0	15.0

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	MW-31						MW-37					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Organics (Continued)												
Acetone	24.0	--	--	--	--	--	--	--	31.0	13.0	--	--
Benzene	5.0J	--	--	--	4.0	3.0	12.0	--	--	9.0	20.0	9.0
Bis(2-chloroethyl)ether	--	--	--	--	--	--	--	--	--	76.0	96.0	--
Bis(2-ethylhexyl)phthalate	10.0J	--	--	--	--	--	24000	6.0J	--	--	--	--
Chlorobenzene	--	--	--	5.0	9.0	8.0	--	--	--	280.0	320.0E	52.0
Chloroethane	--	--	--	--	5.0	--	--	--	--	--	3.0	--
Diethylphthalate	--	4.0J	30	10.0	38.0	41.0	15.0	19.0	29.0	30.0	130.0	76.0
Dimethylphthalate	--	--	--	--	--	--	--	--	--	--	--	25.0
Dichlorodifluoromethane	--	--	--	--	3.0	--	--	--	--	--	--	--
Di-n-octylphthalate	17.0	21.0	2.0J	--	--	--	--	--	--	--	--	--
Ethyl benzene	--	--	--	--	--	--	19.0	26.0	9.0	23.0	34.0E	4.0
Isopropylbenzene	--	--	--	--	3.0	2.0	--	--	--	--	6.0	4.0
p-Isopropyltoluene	--	--	--	--	--	--	--	--	--	--	4.0	--
Methylene chloride	--	--	2.0J	7.0B	2.0	0.9	--	--	--	6.0B	4.0	3.0
Naphthalene	--	--	--	--	3.0B	--	--	--	--	--	7.0	2.0
Tetrachloroethene	--	--	--	--	--	--	5.0J	--	--	--	--	--
Toluene	--	--	--	--	0.5	--	6.0	1.0J	--	--	22.0	2.0
Trichloroethene	--	1.0J	--	--	0.6B	--	--	--	--	--	1.0	5.0
Vinyl chloride	--	--	--	8.0J	15.0	--	--	--	--	--	4.0	--
Xylene (total)	--	--	--	--	2.0	0.7	38.0	--	--	--	14.0	3.0

Table 5-4

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	MW-39						MW-53					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	9	4.7	3.1	5.4	8.2	29.7	170	140	520	b	b	137
Barium	2700	1600	2000	2000	2110	2550	8300	12000	17000	b	b	9470
Cadmium	5	--	--	--	--	--	23	--	51	b	b	--
Chromium	--	--	--	--	--	--	58	--	14	b	b	--
Mercury	--	0.15	--	--	--	--	--	--	--	b	b	--
Lead	35	--	--	--	--	--	100	10	120	b	b	--
Nickel	68	--	--	38.5B	40.1	64.5	520	--	--	b	b	66.5
Selenium	--	0.4	--	--	--	--	--	--	--	b	b	--
Silver	--	--	--	--	--	--	--	--	--	b	b	--
Zinc	90	26	26	--	--	c	1200	140	1100	b	b	c
Organics												
1,1-Dichloroethane	6.0	14.0	21.0	18.0	18.0	18.0	--	7.0	6.0	b	b	--
1,2-Dichloroethene	--	--	--	56.0	0.7	3.0	--	--	--	b	b	--
1,2,3-Trichlorobenzene	--	--	--	--	--	--	--	--	--	b	b	--
1,2,4-Trichlorobenzene	--	--	--	--	--	--	--	--	--	b	b	--
1,2,4-Trimethylbenzene	--	--	--	--	--	--	--	--	--	b	b	--
1,2-Dichlorobenzene	--	--	--	--	3.0	3.0	--	--	--	b	b	--
1,2-Dichloroethane	--	--	--	--	3.0	--	--	--	--	b	b	--
Cis-1,2-dichloroethene	--	--	--	--	180.0E	110.0	--	--	--	b	b	--
Trans-1,2-dichloroethene	--	--	--	--	2.0	--	--	--	--	b	b	--
1,2-Dichloropropane	--	--	--	--	0.7	--	--	--	--	b	b	--
1,3,5-Trimethylbenzene	--	--	--	--	--	--	--	--	--	b	b	--
1,3-Dichlorobenzene	--	--	--	--	0.5	--	--	--	--	b	b	--
1,4-Dichlorobenzene	10.0J	--	--	--	3.0	3.0	20.0J	18.0	6.0J	b	b	5.0J
2,2-Dichloropropane	--	--	--	--	--	--	--	--	--	b	b	--
2,4-Dimethylphenol	--	--	--	--	--	--	--	--	--	b	b	--

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	MW-39						MW-53					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Organics (Continued)												
Acetone	160.0	20.0	--	--	--	--	100.0	--	--	b	b	--
Benzene	--	--	--	--	2.0	2.0	--	--	7.0	b	b	--
Bis(2-chloroethyl)ether	--	--	--	--	--	--	--	--	--	b	b	--
Bis(2-ethylhexyl)phthalate	14.0	5.0	--	--	--	2.0J	20.0J	3.0J	5.0J	b	b	3.0J
Chlorobenzene	--	--	--	140.0	7.0	9.0	--	--	--	b	b	--
Chloroethane	--	--	--	--	3.0	--	--	--	--	b	b	--
Diethylphthalate	--	--	--	--	--	3.0J	26.0	12.0	--	b	b	16.0
Dimethylphthalate	--	--	--	--	--	3.0J	--	--	--	b	b	78.0
Dichlorodifluoromethane	--	--	--	--	87.0E	--	--	--	--	b	b	--
Di-n-octylphthalate	--	--	--	--	--	--	20.0J	2.0J	--	b	b	--
Ethyl benzene	--	1.0J	--	--	--	--	--	23.0	10.0	b	b	--
Isopropylbenzene	--	--	--	--	--	--	--	--	--	b	b	--
p-Isopropyltoluene	--	--	--	--	--	--	--	--	--	b	b	--
Methylene chloride	11.0	5.0	22.0	19.0B	7.0B	5.0	--	--	9.0	b	b	--
Naphthalene	--	--	--	--	3.0B	--	--	--	--	b	b	4.0J
Tetrachloroethene	--	--	--	7.0	11.0	--	--	--	--	b	b	--
Toluene	12.0	3.0J	2.0J	--	--	--	--	10.0	3.0J	b	b	--
Trichloroethene	--	10.0	15.0	24.0	19.0	15.0	--	--	--	b	b	--
Vinyl chloride	--	--	--	20.0	130.0	--	--	--	--	b	b	--
Xylene (total)	--	0.7J	1.0J	--	0.5	--	--	8.0	11.0	b	b	--

Table 5-4

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	MW-55B						MW-56B					
	1986	1988	1989	1991	1992	1994[a]	1987	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	8.1	--	--	b	--	--	1.8	1.9	--	b	--	--
Barium	--	150	100	b	65.3	70.2	-	130	87	b	40.2	56.0
Cadmium	--	--	--	b	--	--	--	--	--	b	--	--
Chromium	--	--	33	b	--	56.6	--	6.8	--	b	--	--
Mercury	--	0.19	--	b	--	--	--	0.12	--	b	--	--
Lead	48	--	--	b	--	--	30	--	10	b	--	--
Nickel	58	--	--	b	406	878	30	--	--	b	--	--
Selenium	1.0	3.1	1.4	b	3.7	--	2.2	1.2	0.16	b	-	--
Silver	--	--	--	b	--	--	--	--	--	b	--	--
Zin	120	--	--	b	--	c	40	24	--	b	--	c
Organics												
1,1-Dichloroethane	11.0	--	--	b	--	--	--	--	--	b	--	--
1,2-Dichloroethene	--	--	--	b	--	--	--	--	--	b	--	--
1,2,3-Trichlorobenzene	--	--	--	b	--	--	--	--	--	b	--	--
1,2,4-Trichlorobenzene	--	--	--	b	--	--	--	--	--	b	--	--
1,2,4-Trimethylbenzene	--	--	--	b	--	--	--	--	--	b	--	--
1,2-Dichlorobenzene	--	--	--	b	--	--	--	--	--	b	--	--
1,2-Dichloroethane	--	--	--	b	--	--	--	--	--	b	--	--
Cis-1,2-dichloroethene	--	--	--	b	--	--	--	--	--	b	--	--
Trans-1,2-dichloroethene	--	--	--	b	--	--	--	--	--	b	--	--
1,2-Dichloropropane	--	--	--	b	0.8	1.0	--	--	--	b	--	--
1,3,5-Trimethylbenzene	--	--	--	b	--	--	--	--	--	b	--	--
1,3-Dichlorobenzene	--	--	--	b	--	--	--	--	--	b	--	--
1,4-Dichlorobenzene	--	--	--	b	--	--	--	--	--	b	--	--
2,2-Dichloropropane	--	--	--	b	--	--	--	--	--	b	--	--

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	MW-55B						MW-56B					
	1986	1988	1989	1991	1992	1994[a]	1987	1988	1989	1991	1992	1994[a]
Organics (Continued)												
2,4-Dimethylphenol	--	--	--	b	--	--	--	--	--	b	--	--
Acetone	25.0	--	--	b	--	--	4.0J	--	15.0	b	--	--
Benzene	--	--	--	b	2.0	--	94.0	--	--	b	0.8	--
Bis(2-chloroethyl)ether	--	--	--	b	--	--	--	--	--	b	--	--
Bis(2-ethylhexyl)phthalate	5.0J	5.0	--	b	--	30 J	3.0J	4.0J	--	b	--	2.0J
Chlorobenzene	--	--	--	b	--	--	--	--	--	b	--	--
Chloroethane	--	--	--	b	--	--	--	--	--	b	--	--
Diethylphthalate	4.0J	--	--	b	--	--	3.0J	4.0J	--	b	--	--
Dimethylphthalate	--	--	--	b	29.0	--	--	--	--	b	4.0J	--
Dichlorodifluoromethane	--	--	--	b	--	--	--	--	--	b	--	--
Di-n-octylphthalate	--	4.0	--	b	--	--	--	8.0J	1.0J	b	--	--
Ethyl benzene	--	--	--	b	--	--	--	--	--	b	--	--
Isopropylbenzene	--	--	--	b	--	--	--	--	--	b	--	--
p-Isopropyltoluene	--	--	--	b	--	--	--	--	--	b	--	--
Methylene chloride	--	--	24.0	b	0.6B	--	14.0	--	19.0	b	--	--
Naphthalene	--	--	--	b	3.0B	--	--	--	--	b	3.0B	--
Tetrachloroethene	--	--	--	b	--	--	--	--	--	b	--	--
Toluene	10.0	--	--	b	--	--	4.0J	--	--	b	--	--
Trichloroethene	5.0	--	--	b	1.0	1.0	--	4.0J	7.0	b	14.0	18.0
Vinyl chloride	--	--	--	b	--	--	--	--	--	b	--	--
Xylene (total)	7.0	--	--	b	--	--	--	--	--	b	--	--

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	MW-57B						MW-63B					
	1986	1988	1989	1991	1992	1994a	'986	1988	1989	1991	1992	1994a
Inorganics												
Arsenic	5.1	8.1	2.2	b	9.6	5.2	b	1.0	--	3.5B	--	--
Barium	3900	1900	3200	b	1010	820	b	610	420	1150	187	230
Cadmium	--	--	16	b	--	--	b	--	--	--	--	--
Chromium	60	11	18	b	--	--	b	20	31	79	--	58.5
Mercury	--	--	--	b	--	--	b	--	--	--	--	--
Lead	90	26	29	b	--	--	b	--	--	6.8	--	--
Nickel	110	--	--	b	--	--	b	--	--	396	294	751
Selenium	--	--	3.5	b	--	--	b	1.1	1.4	--	--	--
Silver	--	--	--	b	--	--	b	--	--	--	--	--
Zinc	80	150	170	b	--	c	b	40	--	35.6	--	c
Organics												
1,1-Dicloroethane	16.0	27.0	20.0	b	3.0	2.0	b	--	--	--	--	--
1,2-Dichloroethene	--	--	--	b	--	--	b	--	--	--	--	--
1,2,3-Trichlorobenzene	--	--	--	b	--	--	b	--	--	--	--	--
1,2,4-Trichlorobenzene	--	--	--	b	--	--	b	--	--	--	--	--
1,2,4-Trimethylbenzene	--	--	--	b	--	--	b	--	--	--	--	--
1,2-Dichlorobenzene	--	--	--	b	--	--	b	--	--	--	--	--
1,2-Dichloroethane	--	--	--	b	--	--	b	--	--	--	--	--
Cis-1,2-dichloroethene	--	--	--	b	3.0	2.0	b	--	--	--	--	--
Trans-1,2-dichloroethene	--	--	--	b	--	--	b	--	--	--	--	--
1,2-Dichloropropane	--	--	--	b	--	--	b	--	--	--	--	--
1,3,5-Trimethylbenzene	--	--	--	b	--	--	b	--	--	--	--	--
1,3-Dichlorobenzene	--	--	--	b	--	--	b	--	--	--	--	--
1,4-Dichlorobenzene	--	--	--	b	--	--	b	--	--	--	--	--
2,2-Dichloropropane	--	--	--	b	--	--	b	--	--	--	--	--
2,4-Dimethylphenol	--	--	--	b	--	--	b	--	--	--	--	--

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	MW-57B						MW-63B					
	1986	1988	1989	1991	1992	1994a	'986	1988	1989	1991	1992	1994a
Organics (Continued)												
Acetone	69.0	--	--	b	--	--	b	--	--	--	--	--
Benzene	3.0J	3.0J	--	b	0.8	0.6	b	--	--	--	--	--
Bis(2-chloroethyl)ether	--	--	--	b	--	--	b	--	--	--	--	--
Bis(2-ethylhexyl)phthalate	--	--	--	b	--	--	b	--	--	--	--	--
Chlorobenzene	--	--	--	b	--	--	b	--	--	--	--	--
Chloroethane	--	--	--	b	1.0	--	b	--	--	--	--	--
Diethylphthalate	--	2.0J	--	b	--	--	b	--	--	--	--	--
Dimethylphthalate	--	--	--	b	--	26.0	b	--	--	--	--	--
Dichlorodifluoromethane	--	--	--	b	1.0	--	b	--	--	--	--	--
Di-n-octylphthalate	--	--	--	b	--	--	b	--	2.0J	--	--	--
Ethyl benzene	--	--	--	b	--	--	b	--	--	--	--	--
Isopropylbenzene	--	--	--	b	--	--	b	--	--	--	--	--
p-Isopropyltoluene	--	--	--	b	--	--	b	--	--	--	--	--
Methylene chloride	120.0	7.0	7.0	b	7.0	--	b	--	--	15.0B	--	--
Naphthalate	--	--	--	b	5.0B	--	b	--	--	--	--	--
Tetrachloroethene	--	--	--	b	--	--	b	--	--	--	--	--
Toluene	--	14.0	--	b	--	--	b	--	--	--	--	--
Trichloroethene	5.0	12.0	6.0	b	3.0	6.0	b	--	--	--	--	1.0
Vinyl chloride	--	--	--	b	10.0	--	b	--	--	--	--	--
Xylene (total)	--	--	--	b	--	--	b	--	--	--	--	--

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	MW-64B						MW-65B					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	b	1.8	--	b	--	--	b	1.6	--	--	--	--
Barium	b	360	220	b	135	131	b	1400	570	425	357	410
Cadmium	b	--	--	b	--	--	b	--	--	--	--	--
Chromium	b	72	44	b	--	98.5	b	9.8	--	--	--	--
Mercury	b	--	--	b	--	--	b	--	--	--	--	--
Lead	b	--	--	b	--	--	b	19	--	--	--	--
Nickel	b	--	--	b	71.1	86.5	b	--	--	27.5B	203	--
Selenium	b	0.8	--	b	--	--	b	0.5	--	--	--	--
Silver	b	--	--	b	--	--	b	--	--	--	--	--
Zinc	b	66	--	b	--	c	b	38	--	23.9	--	c
Organics												
1,1-Dicboroethane	b	--	--	b	--	--	b	--	--	--	--	--
1,2-Dicbloroethene	b	--	--	b	--	--	b	--	--	--	--	--
1,2,3-Trichlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--
1,2,4-Trichlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--
1,2,4-Trimethylbenzene	b	--	--	b	--	--	b	--	--	--	--	--
1,2-Dichlorobenzene	b	--	--	b	--	--	b	--	--	--	1.0	--
1,2-Dichloroethane	b	--	--	b	--	--	b	--	--	--	--	--
Cis-1,2-dichloroethene	b	--	--	b	--	--	b	--	--	--	--	--
Trans-1,2-dichloroethene	b	--	--	b	--	--	b	--	--	--	--	--
1,2-Dichloropropane	b	--	--	b	--	--	b	--	--	--	--	--
1,3,5-Trimethylbenzene	b	--	--	b	--	--	b	--	--	--	--	--
1,3-Dichlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--
1,4-Dichlorobenzene	b	--	--	b	--	--	b	--	--	--	0.5	--
2,2-Dichloropropane	b	--	--	b	--	--	b	--	--	--	--	--

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	MW-64B						MW-65B					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Organics (Continued)												
2,4-Dimethylphenol	b	--	--	b	--	--	b	--	--	--	--	--
Acetone	b	--	--	b	--	--	b	--	39.0	--	--	--
Benzene	b	--	--	b	--	--	b	--	--	--	--	--
Bis(2-chloroethyl)ether	b	--	--	b	--	--	b	--	--	--	--	--
Bis(2-ethylhexyl)phthalate	b	--	--	b	--	14.0	b	8.0J	2.0J	--	1.0J	10.0
Chlorobenzene	b	--	--	b	--	--	b	--	--	--	6.0	--
Chloroethane	b	--	--	b	--	--	b	--	--	--	--	--
Diethylphthalate	b	--	--	b	--	--	b	--	--	--	--	--
Dimethylphthalate	b	--	--	b	--	--	b	--	--	--	17.0	11.0
Dichlorodifluoromethane	b	--	--	b	--	--	b	--	--	--	--	--
Di-n-octylphthalate	b	12.0	--	b	--	--	b	--	--	--	--	--
Ethyl benzene	b	--	--	b	--	--	b	--	--	--	--	--
Isopropylbenzene	b	--	--	b	--	--	b	--	--	--	--	--
p-Isopropyltoluene	b	--	--	b	--	--	b	--	--	--	--	--
Methylene chloride	b	4.0J	5.0B	b	5.0	--	b	10.0B	--	--	--	--
Naphthalate	b	--	--	b	3.0B	--	b	--	--	--	--	--
Tetrachloroethene	b	--	--	b	--	--	b	--	--	--	--	--
Toluene	b	--	--	b	3.0	--	b	--	--	--	--	--
Trichloroethene	b	--	--	b	--	--	b	--	--	--	0.7	--
Vinyl chloride	b	--	--	b	--	--	b	--	--	--	--	--
Xylene (total)	b	--	--	b	--	--	b	--	--	--	--	--

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	MW-66B						MW-67B						MW-1-1S
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]	1994[a]
Inorganics													
Arsenic	b	--	1.2	b	--	--	b	1.4	--	--	--	3.1	--
Barium	b	320	300	b	234	121	b	620	290	230	232	268	73.7
Cadmium	b	--	--	b	--	--	b	--	--	--	--	--	--
Chromium	b	--	--	b	--	24.0	b	5.2	18	--	--	98.8	--
Mercury	b	--	--	b	--	--	b	--	--	--	--	--	--
Lead	b	--	13	b	--	--	b	--	--	--	--	3.8	--
Nickel	b	--	--	b	--	--	b	--	--	10.5B	--	105	--
Selenium	b	1.3	--	b	--	--	b	0.8	--	--	--	--	--
Silver	b	--	--	b	--	--	b	--	--	--	--	--	--
Zinc	b	90	--	b	--	c	b	47	7	--	--	c	c
Organics													
1,1-Dichloroethane	b	--	--	b	--	--	b	--	--	--	--	--	--
1,2-Dichloroethene	b	--	--	b	--	--	b	--	--	--	--	--	--
1,2,3-Trichlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--	--
1,2,4-Trichlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--	--
1,2,4-Trimethylbenzene	b	--	--	b	--	--	b	--	--	--	--	--	--
1,2-Dichlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--	--
1,2-Dichloroethane	b	--	--	b	--	--	b	--	--	--	--	--	--
Cis-1,2-dichloroethene	b	--	--	b	--	--	b	--	--	--	--	--	--
Trans-1,2-dichloroethene	b	--	--	b	--	--	b	--	--	--	--	--	--
1,2-Dichloropropane	b	--	--	b	--	--	b	--	--	--	--	--	--
1,3,5-Trimethylbenzene	b	--	--	b	--	--	b	--	--	--	--	--	--
1,3-Dichlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--	--
1,4-Dichlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--	--
2,2-Dichloropropane	b	--	--	b	--	--	b	--	--	--	--	--	--
2,4-Dimethylphenol	b	--	--	b	--	--	b	--	--	--	--	--	--

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Table 5-4

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	MW-66B						MW-67B						MW-1-1S
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]	1994[a]
Organics (Continued)													
Acetone	b	--	60.0	b	--	--	b	--	--	--	--	--	--
Benzene	b	--	--	b	5.0	--	b	--	--	--	3.0	--	--
Bis(2-chloroethyl)ether	b	--	--	b	--	--	b	--	--	--	--	--	--
Bis(2-ethylhexyl)phthalate	b	--	3.0J	b	--	10.0J	b	--	1.0BJ	36.0	--	7.0J	2.0J
Chlorobenzene	b	--	--	b	--	--	b	--	--	--	--	--	--
Chloroethane	b	--	--	b	--	--	b	--	--	--	--	--	--
Diethylphthalate	b	--	--	b	--	--	b	--	--	--	--	--	--
Dimethylphthalate	b	--	--	b	15.0	--	b	--	--	--	22.0	21.0	10.0
Dichlorodifluoromethane	b	--	--	b	--	--	b	--	--	--	--	--	--
Di-n-octylphthalate	b	--	2.0J	b	--	--	b	--	0.8J	--	--	--	--
Ethyl benzene	b	--	--	b	--	--	b	--	--	--	--	--	--
Isopropylbenzene	b	--	60.0	b	--	--	b	--	--	--	--	--	--
p-Isopropyltoluene	b	--	--	b	5.0	--	b	--	--	--	--	--	--
Methylene chloride	b	--	--	b	--	--	b	--	--	--	--	--	--
Naphthalate	b	--	--	b	--	--	b	--	--	--	--	--	--
Tetrachloroethene	b	--	--	b	--	--	b	--	--	--	--	--	--
Toluene	b	--	2.0J	b	--	--	b	--	--	--	--	--	--
Trichloroethene	b	--	--	b	2.0	0.6	b	--	--	--	2.0	1.0	5
Vinyl chloride	b	--	--	b	--	--	b	--	--	--	--	--	--
Xylene (total)	b	--	3.0J	b	--	--	b	--	--	--	--	--	--

[a]February 1994 sampling round data is available in preliminary form for select Landfill 6 wells. Data is preliminary and has not undergone a formal validation process and is therefore subject to modification.
[b]No data available for this analytical suite for period shown
[c]Data for this analyte not available or element/compound was not analyzed.
-- = Analyte not detected above contract-required detection limits (CRDL). Actual detection limits in effect at time of analysis may be greater than the CRDL for a particular analyte if dilution of the sample was necessary.
J = Presence of analyte is reliable; value shown is an estimated quantity.
B = Analyte found in associated blank as well as in the sample.
E = Value shown is outside calibration range.

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Table 5-5

Summary of 1986 through 1989, 1991, 1992, 1994 Analytical Results
Lower Saturated Zone Monitoring Wells,
(Concentrations in µg/L)
SWMU-1, Landfill 6, Tinker AFB

(Page 1 of 14)

	MW-26						MW-28					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	8.7	2.5	2.4	3.2 B	--	--	5.0	b	--	2.1 B	--	--
Barium	19000	1100	1100	785	833	700	--	b	--	332	318	280
Cadmium	15	--	--	--	--	--	13	b	--	--	--	--
Chromium	270	19	--	--	--	--	20	b	--	--	--	--
Mercury	--	--	--	--	--	--	--	b	--	--	--	--
Lead	280	17	--	--	--	3.7	68	b	--	--	--	21.6
Nickel	180	--	--	--	--	--	58	b	--	--	--	--
Selenium	--	0.8	--	--	--	--	--	b	--	--	--	--
Silver	--	10	--	--	--	--	--	b	--	--	--	--
Zinc	220	100	54	52.7	--	c	53	b	16	102	--	c
Organics												
1,1-Dichloroethane	--	--	--	--	--	--	--	b	--	--	--	--
1,2,4-Trimethylbenzene	--	--	--	--	--	--	--	b	--	--	--	--
1,2-Dichlorobenzene	--	--	--	--	0.5	--	--	b	--	--	--	--
cis-1,2-Dichloroethene	--	--	--	--	--	--	--	b	--	--	--	--
1,4-Dichlorobenzene	--	--	--	--	--	--	--	b	--	--	--	--
Acetone	--	--	--	--	--	--	--	b	--	--	--	--

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Table 5-5

	MW-26						MW-28					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Organics (Continued)												
Benzene	--	--	--	--	1.0	--	12.0	b	--	--	--	--
Bis(2-ethylhexyl)phthalate	10.0 J	--	--	--	--	9.0 J	--	b	--	--	--	24.0
Chlorobenzene	--	--	--	--	0.8	--	--	b	--	--	--	--
Dimethylphthalate	--	--	--	--	5.0 J	510 E	--	b	--	--	--	270 E
Di-n-octylphthalate	--	--	--	--	--	--	--	b	--	--	--	--
Ethylbenzene	--	--	--	--	0.9	--	--	b	--	--	--	--
Isopropylbenzene	--	--	--	--	3.0	--	--	b	--	--	--	--
Methylene Chloride	--	--	3.0 BJ	15.0 B	0.8 B	--	--	b	7.0	5.0 B	0.6 B	--
Naphthalene	--	--	--	--	2.0 B	--	--	b	--	--	--	--
n-Propylbenzene	--	--	--	--	--	--	--	b	--	--	--	--
Tetrachloroethene	--	--	--	--	1.0	--	--	b	--	--	--	--
Toluene	--	--	--	--	--	--	--	b	--	--	--	--
Trichloroethene	5.0 J	--	36.0	--	3.0	6.0	6.0	b	--	--	--	4.0
Vinyl Chloride	--	--	--	--	--	--	--	b	--	--	--	--
Xylenes (Total)	--	--	--	--	--	--	--	b	--	--	--	--

Table 5-5

(Page 3 of 14)

	MW-36						MW-38					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	3.8	3.3	4.9	b	3.1	4.3	2.0	2.7	1.0	2.0 B	--	--
Barium	960	1100	1500	b	937	903	2300	690	460	484	434	410
Cadmium	5.0	--	--	b	--	--	10	9.0	--	--	--	--
Chromium	--	21	26	b	--	--	70	10	--	--	--	--
Mercury	--	--	--	b	--	--	0.12	0.12	--	--	--	--
Lead	50	--	12	b	--	--	85	31	--	--	--	--
Nickel	35	--	--	b	--	--	50	--	--	--	--	--
Selenium	1.4	1.8	--	b	--	--	--	--	0.8	--	--	--
Silver	--	--	--	b	--	--	--	--	--	--	--	--
Zinc	110	59	44	b	--	c	120	24	35	34	--	c
Organics												
1,1-Dichloroethane	--	--	--	b	--	--	--	--	--	--	--	--
1,2,4-Trimethylbenzene	--	--	--	b	--	--	--	--	--	--	--	--
1,2-Dichlorobenzene	--	--	--	b	0.7	--	--	--	--	--	0.8	--
cis-1,2-Dichloroethene	--	--	--	b	0.8	0.5	--	--	--	--	--	--
1,4-Dichlorobenzene	45.0	--	--	b	--	--	--	--	--	--	--	--
Acetone	--	--	24.0	b	--	--	720	--	--	--	--	--
Benzene	--	--	--	b	--	--	--	--	--	--	15.0	--
Bis(2-ethylhexyl)phthalate	10.0 J	--	10.0	b	--	8.0 J	46.0	6.0 J	4.0 J	29.0	--	43.0
Chlorobenzene	--	--	--	b	2.0	--	--	--	--	--	4.0	--
Dimethylphthalate	--	--	--	b	--	97.0 E	--	--	--	--	14.0	42.0

Table 5-5

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	MW-36						MW-38					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Organics (Continued)												
Di-n-octylphthalate	--	--	2.0 J	b	--	--	10.0 J	13.0	3.0 J	--	--	--
Ethylbenzene	--	--	--	b	--	--	--	--	--	--	4.0	--
Isopropylbenzene	--	--	--	b	--	--	--	--	--	--	8.0	--
Methylene Chloride	--	--	13.0 B	b	0.7	--	5.0 J	--	8.0	5.0 B	--	--
Napthalene	--	--	--	b	--	--	--	--	--	--	--	--
n-Propylbenzene	--	--	--	b	--	--	--	--	--	--	--	--
Tetrachloroethene	--	--	--	b	--	--	--	--	--	--	0.8	--
Toluene	--	--	--	b	--	--	17.0	--	--	--	0.5	--
Trichloroethene	--	--	--	b	1.0	3.0	41.0	--	--	--	6.0	2.0
Vinyl Chloride	--	--	--	b	--	--	--	--	--	--	--	--
Xylenes (Total)	--	--	--	b	--	--	--	--	--	--	1.0	--

Table 5-5

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	MW-55A						MW-55C					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	b	1.4	--	b	b	b	b	b	b	b	--	--
Barium	b	440	430	b	b	b	b	b	b	b	461	209
Cadmium	b	--	--	b	b	b	b	b	b	b	--	--
Chromium	b	12	--	b	b	b	b	b	b	b	--	--
Mercury	b	--	--	b	b	b	b	b	b	b	--	--
Lead	b	--	--	b	b	b	b	b	b	b	--	--
Nickel	b	--	--	b	b	b	b	b	b	b	18.7	--
Selenium	b	0.8	--	b	b	b	b	b	b	b	--	--
Silver	b	--	--	b	b	b	b	b	b	b	--	--
Zinc	b	--	25	b	b	b	b	b	b	b	--	c
Organics												
1,1-Dichloroethane	b	--	--	b	b	b	b	b	b	b	--	--
1,2,4-Trimethylbenzene	b	--	--	b	b	b	b	b	b	b	--	--
1,2-Dichlorobenzene	b	--	--	b	b	b	b	b	b	b	1.0	--
cis-1,2-Dichloroethene	b	--	--	b	b	b	b	b	b	b	3.0	--
1,4-Dichlorobenzene	b	--	--	b	b	b	b	b	b	b	--	--
Acetone	b	--	--	b	b	b	b	b	b	b	--	--
Benzene	b	--	--	b	b	b	b	b	b	b	13.0	--
Bis(2-ethylhexyl)phthalate	b	--	18.0 B	b	b	b	b	b	b	b	--	48.0
Chlorobenzene	b	--	--	b	b	b	b	b	b	b	3.0	--
Dimethylphthalate	b	--	--	b	b	b	b	b	b	b	14.0	260.0 E

Table 5-5

	MW-55A						MW-55C					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Organics (Continued)												
Di-n-octylphthalate	b	--	2.0 J	b	b	b	b	b	b	b	--	20.0
Ethylbenzene	b	--	--	b	b	b	b	b	b	b	3.0	--
Isopropylbenzene	b	--	--	b	b	b	b	b	b	b	10.0	--
Methylene Chloride	b	--	--	b	b	b	b	b	b	b	--	--
Naphthalene	b	--	--	b	b	b	b	b	b	b	2.0 B	--
n-Propylbenzene	b	--	--	b	b	b	b	b	b	b	--	--
Tetrachloroethene	b	--	--	b	b	b	b	b	b	b	0.6	--
Toluene	b	--	--	b	b	b	b	b	b	b	0.6	--
Trichloroethene	b	--	--	b	b	b	b	b	b	b	6.0	3.0
Vinyl Chloride	b	--	--	b	b	b	b	b	b	b	--	--
Xylenes (Total)	b	--	--	b	b	b	b	b	b	b	0.9	--

Table 5-5

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	MW-56A						MW-57A					
	1987	1988	1989	1991	1992	1994[a]	1987	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	1.5	4.2	12.0	b	--	6.2	6.7	3.3	--	b	--	--
Barium	--	240	320	b	51	78.1	530	1100	330	b	546	466
Cadmium	--	--	--	b	--	--	--	--	--	b	--	--
Chromium	--	7.0	23	b	--	31.6	20	26	26	b	--	--
Mercury	--	--	--	b	--	--	--	--	--	b	--	--
Lead	40	18	35	b	--	--	43	18	--	b	--	--
Nickel	25	--	--	b	--	--	30	--	--	b	378	231
Selenium	1.8	1.5	2.0	b	2.2	--	--	--	--	b	--	--
Silver	--	--	--	b	--	--	--	--	--	b	--	--
Zinc	100	--	210	b	--	c	75	22	20	b	--	c
Organics												
1,1-Dichloroethane	--	--	--	b	0.9	--	--	--	--	b	--	--
1,2,4-Trimethylbenzene	--	--	--	b	0.8	--	--	--	--	b	--	--
1,2-Dichlorobenzene	--	--	--	b	3.0	--	--	--	--	b	1.0	--
cis-1,2-Dichloroethene	--	--	--	b	17.0	--	--	--	--	b	1.0	--
1,4-Dichlorobenzene	--	--	--	b	0.9	--	--	--	--	b	0.5	--
Acetone	--	--	--	b	--	170	--	--	--	b	--	--
Benzene	62.0	--	--	b	89.0 E	--	5.0 J	--	--	b	15.0	--
Bis(2-ethylhexyl)phthalate	7.0 J	19.0	--	b	18.0	3.0 J	--	--	100.0 B	b	2.0 J	12.0
Chlorobenzene	--	--	--	b	10.0	--	--	--	--	b	3.0	--
Dimethylphthalate	--	--	--	b	5.0 J	37.0	--	--	--	b	61.0	23.0

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Table 5-5

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	MW-56A						MW-57A					
	1987	1988	1989	1991	1992	1994[a]	1987	1988	1989	1991	1992	1994[a]
Organics (Continued)												
Di-n-octylphthalate	--	--	--	b	--	--	1.9 J	--	3.0 J	b	--	--
Ethylbenzene	--	--	--	b	9.0	--	--	--	--	b	4.0	--
Isopropylbenzene	--	--	--	b	21.0	--	--	--	--	b	10.0	--
Methylene Chloride	--	--	5.0	b	--	--	--	10.0	10.0	b	0.6	--
Napthalene	--	--	--	b	1.0 B	--	--	--	--	b	4.0 B	--
n-Propylbenzene	--	--	--	b	0.6	--	--	--	--	b	--	--
Tetrachloroethene	--	--	--	b	2.0	--	--	--	--	b	0.7	--
Toluene	--	1.0 J	--	b	3.0	--	--	--	--	b	1.0	--
Trichloroethene	--	4.0 J	2.0 J	b	30.0 E	7.0	--	--	--	b	8.0 B	6.0
Vinyl Chloride	--	--	--	b	0.5	--	--	--	--	b	--	--
Xylenes (Total)	--	--	--	b	4.2	--	--	--	--	b	1.0	--

Table 5-5

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	MW-63A						MW-64A					
	1986	1988	1989	1991	1992	1994[a]	1986	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	b	2.0	1.2	2.1 B	2.2	--	b	2.0	--	b	--	--
Barium	b	600	340	198 B	327	359	b	710	420	b	322	1210
Cadmium	b	--	--	--	--	--	b	--	--	b	--	--
Chromium	b	18	590	--	--	--	b	17	5.5	b	--	--
Mercury	b	--	--	--	--	--	b	--	--	b	--	--
Lead	b	--	--	--	--	--	b	--	--	b	--	--
Nickel	b	--	--	140	64	65.4	b	--	--	b	114	56.8
Selenium	b	1.5	3.4	--	--	--	b	1.1	--	b	--	--
Silver	b	--	--	--	--	--	b	--	--	b	--	--
Zinc	b	99	27	--	--	c	b	50	--	b	--	c
Organics												
1,1-Dichloroethane	b	--	--	--	--	--	b	--	--	b	4.0	1.0
1,2,4-Trimethylbenzene	b	--	--	--	--	--	b	--	--	b	--	--
1,2-Dichlorobenzene	b	--	--	--	0.5	--	b	--	--	b	1.0	--
cis-1,2-Dichloroethene	b	--	--	--	--	--	b	--	--	b	1.0	--
1,4-Dichlorobenzene	b	--	--	--	--	--	b	--	--	b	--	--
Acetone	b	--	--	--	--	--	b	--	--	b	--	--
Benzene	b	--	--	--	--	--	b	--	--	b	25.0	--
Bis(2-ethylhexyl)phthalate	b	--	--	--	--	5.0 J	b	--	--	b	--	27.0
Chlorobenzene	b	--	--	--	4.0	--	b	--	--	b	6.0	--
Dimethylphthalate	b	--	--	--	--	59.0	b	--	--	b	5.0 J	--

Table 5-5

	MW-63A						MW-64A					
	1986	1988	1989	1991	1992	1994	1987	1988	1989	1991	1992	1994[a]
Organics (Continued)												
Di-n-octylphthalate	b	--	3.0 BJ	--	--	--	b	12.0	--	b	--	--
Ethylbenzene	b	--	--	--	--	--	b	--	--	b	6.0	--
Isopropylbenzene	b	--	--	--	--	--	b	--	--	b	11.0	--
Methylene Chloride	b	--	--	18.0 B	--	--	b	4.0 J	6.0 B	b	--	--
Naphtalene	b	--	--	--	--	--	b	--	--	b	--	--
n-Propylbenzene	b	--	--	--	--	--	b	--	--	b	--	--
Tetrachloroethene	b	--	--	--	--	--	b	--	--	b	1.0	--
Toluene	b	--	--	--	--	--	b	--	--	b	0.5	--
Trichloroethene	b	--	--	--	--	2.0	b	--	--	b	9.0	3.0
Vinyl Chloride	b	--	--	--	--	--	b	--	--	b	--	--
Xylenes (Total)	b	--	--	--	--	--	b	--	--	b	2.0	--

Table 5-5

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	MW-65A						MW-66A					
	1986	1988	1989	1991	1992	1994[a]	1987	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	b	3.2	--	2.1 B	2.2	--	b	b	b	b	--	8.6
Barium	b	840	450	654	405	501	b	b	b	b	137	1980
Cadmium	b	--	--	--	--	--	b	b	b	b	--	150
Chromium	b	10	--	--	--	27.3	b	b	b	b	--	1270
Mercury	b	--	--	--	--	--	b	b	b	b	--	--
Lead	b	25	10	1.1 B	--	6.4	b	b	b	b	--	10.9
Nickel	b	--	--	9.8 B	17.8	--	b	b	b	b	2350	2110
Selenium	b	0.4	--	--	2.5	--	b	b	b	b	--	--
Silver	b	--	--	--	--	--	b	b	b	b	--	--
Zinc	b	160	10	--	--	c	b	b	b	b	--	c
Organics												
1,1-Dichloroethane	b	--	--	--	0.6	--	b	b	b	b	--	--
1,2,4-Trimethylbenzene	b	--	--	--	--	--	b	b	b	b	--	--
1,2-Dichlorobenzene	b	--	--	--	--	--	b	b	b	b	--	--
cis-1,2-Dichloroethene	b	--	--	--	0.8	--	b	b	b	b	0.9	--
1,4-Dichlorobenzene	b	--	--	--	--	--	b	b	b	b	--	--
Acetone	b	--	--	--	--	--	b	b	b	b	--	--
Benzene	b	--	--	--	3.0	--	b	b	b	b	5.0	--
Bis(2-ethylhexyl)phthalate	b	--	--	--	--	22.0	b	b	b	b	2.0 J	--
Chlorobenzene	b	--	--	--	2.0	--	b	b	b	b	1.0	1.0
Dimethylphthalate	b	--	--	--	--	130.0 E	b	b	b	b	63.0	150.0 E

Table 5-5

	MW-65A						MW-66A					
	1986	1988	1989	1991	1992	1994[a]	1987	1988	1989	1991	1992	1994
Organics (Continued)												
Di-n-octylphthalate	b	--	--	--	--	--	b	b	b	b	--	--
Ethylbenzene	b	--	--	--	--	--	b	b	b	b	--	--
Isopropylbenzene	b	--	--	--	--	--	b	b	b	b	0.7	--
Methylene Chloride	b	6.0 B	3.0 BJ	6.0 B	2.0 B	--	b	b	b	b	--	--
Napthalene	b	--	--	--	3.0 B	--	b	b	b	b	3.0 B	--
n-Propylbenzene	b	--	--	--	--	--	b	b	b	b	--	--
Tetrachloroethene	b	--	--	--	--	--	b	b	b	b	--	1.0
Toluene	b	0.6 J	--	--	--	--	b	b	b	b	0.7	--
Trichloroethene	b	--	--	--	1.0	2.0	b	b	b	b	1.0	27.0
Vinyl Chloride	b	--	--	--	0.9	--	b	b	b	b	--	--
Xylenes (Total)	b	--	--	--	--	--	b	b	b	b	--	--

Table 5-5

(Page 13 of 14)

	MW-67A						MW-1-1D					
	1987	1988	1989	1991	1992	1994[a]	1987	1988	1989	1991	1992	1994[a]
Inorganics												
Arsenic	b	4.0	--	2.0 B	2.1	--	b	b	b	b	b	--
Barium	b	570	410	422	362	926	b	b	b	b	b	765
Cadmium	b	--	--	--	--	--	b	b	b	b	b	--
Chromium	b	--	--	--	--	22.6	b	b	b	b	b	--
Mercury	b	--	--	--	--	--	b	b	b	b	b	--
Lead	b	--	--	1.0 B	--	5.1	b	b	b	b	b	--
Nickel	b	--	--	--	--	--	b	b	b	b	b	--
Selenium	b	0.6	--	--	--	--	b	b	b	b	b	--
Silver	b	--	--	--	--	--	b	b	b	b	b	--
Zinc	b	36	11	202.4	--	c	b	b	b	b	b	c
Organics												
1,1-Dichloroethane	b	--	--	--	--	--	b	b	b	b	b	--
1,2,4-Trimbethylbenzene	b	--	--	--	--	--	b	b	b	b	b	--
1,2-Dichlorobenzene	b	--	--	--	0.6	--	b	b	b	b	b	--
cis-1,2-Dichloroethene	b	--	--	--	--	--	b	b	b	b	b	--
1,4-Dichlorobenzene	b	--	--	--	--	--	b	b	b	b	b	--
Acetone	b	--	--	--	--	--	b	b	b	b	b	--
Benzene	b	--	--	--	8.0	--	b	b	b	b	b	--
Bis(2-ethylhexyl)phthalate	b	--	87.0 B	--	--	16.0	b	b	b	b	b	4.0 J
Chlorobenzene	b	--	--	--	1.0	--	b	b	b	b	b	--
Dimethylphthalate	b	00	00	00	2.0 J	--	b	b	b	b	b	41.0

Table 5-5

(Page 14 of 14)

	MW-67A						MW-1-1D					
	1987	1988	1989	1991	1992	1994[a]	1987	1988	1989	1991	1992	1994[a]
Organics (Continued)												
Di-n-octylphthalate	b	--	0.8 J	--	--	--	b	b	b	b	b	--
Ethylbenzene	b	--	--	--	1.0	--	b	b	b	b	b	--
Isopropylbenzene	b	--	--	--	7.0	--	b	b	b	b	b	--
Methylene Chloride	b	--	5.0	--	--	--	b	b	b	b	b	--
Napthalene	b	--	--	--	--	--	b	b	b	b	b	--
n-Propylbenzene	b	--	--	--	--	--	b	b	b	b	b	--
Tetrachloroethene	b	--	--	--	--	--	b	b	b	b	b	--
Toluene	b	--	--	--	--	--	b	b	b	b	b	--
Trichloroethene	b	--	--	--	2.0	2.0	b	b	b	b	b	3.0
Vinyl Chloride	b	--	--	--	--	--	b	b	b	b	b	--
Xylenes (Total)	b	--	--	--	--	--	b	b	b	b'	b	--

[a]February 1994 sampling round data is available in preliminary form for select Landfill 6 wells. Data is preliminary and has not undergone a formal vbalidation process and is therefore subject to modification.
[b]No data available for this analytical suite for period shown
[c]Data for this analyte not available or element/compound was not analyzed.
-- = Analyte not detected above contract-required detection limits (CRDL). Actual detection limits in effect at time of analysis may be greater than the CRDL for a particular analyte if dilution of the sample was necessary.
J = Presence of analyte is reliable; value shown is an estimated quantity.
B = Analyte found in associated blank as well as in the sample.
E = Value shown is outside calibration range.

Table 5-6

Summary of 1991 and 1992 Analytical Results for Ions/TDS, Select Groundwater Monitoring Wells, SWMU-1, Landfill 6, Tinker AFB

Well	Chloride (mg/L)		Sulfate (mg/L)		TDS (mg/L)	
	1991	1992	1991	1992	1991	1992
1-1S	7.5	15.4	88.8E	74	307E	359
1-2S	10.1E	11.4	78.0	85	358E	449
1-3S	.95E	2.3	238E	143	609E	477
55B	157E	103.1	83E	73	743E	716
56B	147E	99.9	176E	165	901E	899
57B	4.1E	3.1	19.7E	11	908	648
1-1D	22.2	21.3	<0.3	7	366E	404
1-2D	7.5E	6.4	21.8E	19	343E	339
1-3D	8.8E	7.1	6.0E	7	292E	287
26	83.7E	77.9	14.2E	12	567E	527
56A	152E	108.5	137E	142	863E	871
57A	35.6E	27	14.0E	8	372E	305

NOTE: E = Estimated value - samples were analyzed after holding time had expired.

Table 5-7

Summary of Analytical Results
Stream Sediment Samples
SWMU-1, Landfill 6, Tinker AFB

Compound	SS-1	SS-2	SS-3	SS-4	SS-5	SS-6
Metals (mg/kg)						
Arsenic	2.4	2.5	2.6	1.5	1.6	2.7
Barium	330	220	260	110	150	280
Cadmium	0.50	0.69	<0.5	<0.5	<0.5	<0.5
Chromium	10	24	11	8	<5.0	6.6
Lead	11	12	13	4.9	6.2	11
Nickel	10	12	10	6.8	4.8	5
Selenium	6	26	26	30	15	15
Zinc	13	13	11	9.6	6.5	9.7
Organics (μg/kg)						
Methylene chloride	8	12	8	7	<5	<5
Acetone	28	<13	<13	<13	<14	<12

Rose Rock (barium sulphate) occurs as natural deposits in this area of Oklahoma, and has been encountered at other Tinker sites in high concentrations; therefore, barium is considered to be an in situ contaminant and not one introduced by past waste disposal practices (USACE, 1993). Table 5-8 contains the frequency of each metal above background, range of concentrations, average concentration, and location of the maximum concentration.

Thirteen organic compounds were detected in the trench soil samples. The organic compounds were found sporadically throughout the landfill site. Total xylene, toluene, 2-butanone, and acetone were detected in the majority of the trench samples. Total xylene was detected at 170,000 micrograms per kilogram (μg/kg) in trench boring L6-1 and was found in lower concentrations in 14 other samples. Toluene was found in 13 samples with the highest concentration of 9,100 μg/kg. Acetone was found in 9 samples and 2-butanone in 13 samples. Other organic compounds detected in the trench samples included 4-methyl-2-pentanone, ethyl benzene, bis(2-ethylhexyl)phthalate, methylene chloride, 2-hexanone, trichloroethene, tetrachloroethene, chlorobenzene, and naphthalene. Bis(2-ethylhexyl)phthalate concentration in one sample (L6-4) exceeded the SWMU CAL of 50 mg/kg. Table 5-9 contains the frequency of these organics, range of concentrations, average concentrations, and location of maximum concentrations.

5.3 Groundwater Characterization

5.3.1 RI Results

The USZ includes both the groundwater encountered within the landfill trenches and the phreatic groundwater surrounding the landfill. The quality of the groundwater within the landfill trenches and within the surrounding aquifer are discussed in the following paragraphs.

Landfill Trench Water. Five samples of the groundwater encountered while installing the RI trench borings were analyzed to determine the quality of the water in the landfill cells. The samples were taken from trench borings L6-3, L6-5, L6-11, L6-13, and L6-17. A summary of chemical compounds found in the samples is contained in Table 5-3. Full sample results are available in the USACE 1993 RI report.

Metals were detected in each of the samples. Barium was detected in four samples, with an average concentration of 4,450 micrograms per liter (μg/L). Cadmium was detected in all the samples, with an average concentration of 102.5 μg/L. Nickel was detected in each of the samples, with an average concentration of 622 μg/L. Chromium was detected in three

Table 5-8

Frequency of Metals in Trench Soil Samples
SWMU-1, Landfill 6, Tinker AFB

Metal	No. Detected Above Background No. Sampled	Range (mg/kg)	Average Concentration (mg/kg)	Location of Maximum
Silver	2/19	<0.5-11	2.99	L6-4, L6-17
Arsenic	0/19	<1.0-5.1	1.73	L6-3
Barium	2/19	77-150,000	8181	L6-17
Cadmium	16/19	1.3-34	9.8	L6-17
Chromium	3/19	13-230	58.6	L6-16
Mercury	0/19	<0.1-0.89	0.22	L6-16
Nickel	7/19	13-240	75.9	L6-11
Lead	12/19	10-570	96.6	L6-1
Selenium	0/19	<0.1-0.9	0.19	L6-1
Zinc	16/19	29-750	258	L6-17

Table 5-9

Frequency of Organic Compounds In Trench Soil Samples SWMU-1, Landfill 6, Tinker AFB

Compound	No. Detected/ No. Sampled	Range (µg/kg)	Average Concentration (µg/kg)	Location of Maximum
2-Butanone	13/19	<12-6300	1073	L6-4
Ethyl benzene	7/19	<6-24000	1430	L6-1
Total xylenes	15/19	<6-170000	9743	L6-1
4-Methyl-2-pentanone	8/19	<12-2700	595	L6-14
Toluene	13/19	<6-9100	1045	L6-7
Methylene chloride	9/19	<6-2190	180	L6-22
Acetone	9/19	<12-36000	2562	L6-7
2-Hexanone	9/19	<12-450	283	L6-1
Trichloroethene	5/19	<6-160	120	L6-22
Tetrachloroethene	7/19	<6-4800	423	L6-22
Chlorobenzene	4/19	<6-340	147	L6-17
Naphthalene	5/19	<390-31000	6506	L6-2
Bis(2-ethylhexyl)phthalate	16/19	110-75000	10,166	L6-4

samples with an average concentration of 130.6 µg/L. Lead was detected in all samples with an average concentration of 277.8 µg/L. Cadmium concentrations exceeded the MCL of 0.005 milligrams per liter (mg/L) in five samples; lead concentrations exceeded the MCL of 15 mg/L in five samples; and chromium concentrations exceeded the MCL of 10 mg/L in one sample.

Several VOCs and SVOCs were detected in the landfill trench water. Methylene chloride and toluene were detected in four of the five samples, while 2-butanone, 4-methyl-2-pentanone, and 4-methyl phenol were detected in three of the five samples. Several other compounds were detected sporadically throughout the site. Table 5-10 contains the frequency of occurrence of each compound, the maximum concentration, and the location of the maximum concentration. Methylene chloride concentrations exceeded the SWMU CAL of 5 mg/L in three samples; acetone concentrations exceeded the SWMU CAL of 4000 mg/L in one sample; trans-1,2-dichloroethene concentrations exceeded the MCL of 100 mg/L in one sample; 1,2-dichloropropane concentrations exceeded the MCL of 5 mg/L in three samples.

Upper Saturated Zone. The quality of the USZ groundwater in the vicinity of Landfill 6 was determined by laboratory analysis of groundwater from up to 14 site monitoring wells (not all wells were sampled for each sampling event) during the period of 1986 to 1992 (Table 5-4). The results of the laboratory analysis of the samples indicate the presence of some metals, VOCs, and SVOCs above the MCLs and SWMU CALs. The majority of contamination is found to be in the western portion of the landfill site. A summary of the predominant chemical constituents with their frequency of occurrence is provided in Table 5-11.

Metals. The predominant metal contaminants are arsenic, barium, cadmium, lead, and nickel. Barium exhibits the highest concentration levels than all the other detected metals. The maximum concentration was detected in monitoring well MW-37 at 26,000 µg/L, 13 times above the MCL value of 2,000 µg/L. The high concentration of barium may be naturally occurring, due to the migration of groundwater through the sandstone stratum (often called the Oklahoma Rose Rock), which leaches barium sulfate.

Other metallic constituents detected above their respective MCLs include: arsenic, cadmium, lead, and nickel with maximum concentration levels of 250 µg/L, 51 µg/L, 120 µg/L, and 2,350 µg/L respectively (Table 5-4). Arsenic was in highest concentration in monitoring well MW-53, located on the north side of the landfill. The concentration of arsenic in this well

Table 5-10

Frequency of Chemical Constituents in Trench Water Samples SWMU-1, Landfill 6, Tinker AFB

(Page 1 of 2)

Compound	No. Detected/ No. Sampled	Range (µg/L)	Average Concentration (µg/L)	Location of Maximum
Organics				
Methylene chloride	4/5	<6 - 910	299	L6-5
Acetone	2/5	<10 - 4800	1140	L6-17
1,1-dichloroethene	1/5	<5 - 37	10	L6-3
Trans-1,2-dichloroethene	2/5	<5 - 165	45.6	L6-17
2-Butanone	3/5	<10 - 6600	1801	L6-17
1,2-Dichloropropane	1/5	<5 - 21	7.2	L6-3
Trichloroethene	1/5	<5 - 13	5.6	L6-3
2-Hexanone	2/5	<10 - 4400	1422	L6-17
4-Methyl-2-pentanone	3/5	<10 - 200	80	L6-17
Toluene	4/5	<5 - 2600	567	L6-17
Total xylenes	2/5	<5 - 760	161	L6-17
Phenol	1/5	<20 - 110	30	L6-5
2-Methylphenol	1/5	<20 - 270	64	L6-3
4-Methylphenol	3/5	<20 - 2400	900	L6-17
Benzoic acid	1/5	<100 - 1211	602	L6-17

Compound	No. Detected/ No. Sampled	Range (µg/L)	Average Concentration (µg/L)	Location of Maximum
n-Nitrosodipropylamine	1/5	<20 - 190	46	L6-5
Metals				
Arsenic	5/5	3.3 - 28	14.1	L6-5
Barium	4/5	<500 - 8700	4450	L6-5
Cadmium	5/5	7.5 - 480	102.5	L6-17
Chromium	3/5	<10 - 610	130.6	L6-17
Lead	5/5	53 - 1100	277.8	L6-17
Mercury	1/5	<0.4 - 3.8	0.92	L6-17
Nickel	5/5	130 - 1800	622	L6-17
Silver	1/5	<10 - 40	12	L6-17
Zinc	5/5	75 - 6600	13533	L6-17

Table 5-11

Frequency of Chemical Constituents in 1986 through 1988, 1989, 1991, and 1992 USZ Groundwater Samples SWMU-1, Landfill 6, Tinker AFB

(Page 1 of 2)

Compound	No. Detected/ No. Sampled	Range (µg/L)	Average Concentration (µg/L)	Location of Maximum
Metals				
Arsenic	38/57	1.0-520	36.6	53
Barium	55/57	40.2-26000	4345	37
Cadmium	13/57	5-51	13.9	53
Chromium	23/57	5.2-79	26.4	63B
Mercury	6/57	0.1-0.43	<0.1	31
Lead	27/57	1.3B-120	34.3	53
Nickel	24/57	30-1100	276.2	37
Selenium	19/57	0.16-3.7	1.3	55B
Silver	1/57	13	13	30
Zinc	32/57	7-1200	142.6	53
Volatiles				
1,1-Dichloroethane	24/57	3-89	19.6	31
1,2-Dichloroethane	2/57	3-7	5	31
Acetone	14/57	4.0J-2500.0E	311.4	12
Benzene	20/57	0.8-94	10.6	56B
Cis-1,2-dichloroethene	4/57	2-180E	47.8	39
Ethyl benzene	15/57	1.0J-45J	18.3	12
Methylene chloride	31/57	0.6B-120	16.1	57B
Toluene	21/57	0.5-130	15.5	12
Trichloroethene	21/57	0.6B-24	6.7	39
Xylene	18/57	0.5-88	18.9	30
Semivolatiles				
1,4-Dichlorobenzene	20/57	0.5-61	16.8	37
Bis(2-ethylhexyl)phthalate	21/57	1.0J-24000	1,160.7	37

Table 5-11

Compound	No. Detected/ No. Sampled	Range (µg/L)	Average Concentration (µg/L)	Location of Maximum
Bis(2-chloroethyl)ether	2/57	76-96	86	37
Diethyl phthalate	23/57	2.0J-130	33.6	37
Di-n-octyl phthalate	16/57	0.8J-21	7.1	31

B = Analyte found in associated blank as well as in sample.
E = Estimated value - samples were analyzed after holding time had expired.
J = Presence of analyte is reliable; value shown is estimated quantity.

was ten times above the MCL value of 50 μg/L. Another well in which arsenic was detected above the MCL was MW-30, also located on the north side of the landfill. Cadmium and lead were also detected in highest concentrations in monitoring well MW-53. The maximum concentrations were ten and eight times above the MCL values of 5 μg/L and 15 μg/L respectively. Other wells in which cadmium was detected above MCL include: MW-12, MW-30, MW-31, MW-37, and MW-57B. Except for MW-57B, these wells are all located within the landfill area. Nickel was in highest concentration in a sample collected from MW-37, located on the western side of the landfill. The concentration of nickel in this well was 11 times the MCL. Other wells that exhibited nickel levels above the MCL include: MW-12, MW-30, MW-31, MW-53, MW-55B, MW-57B, MW-63B, and MW-65B (Table 5-4).

Of the metals analyzed in samples taken in 1994 from monitoring well MW1-1S, located upgradient of the landfill, only barium was detected at a concentration of 73.7 μg/L, well below the MCL value of 2,000 μg/L. Two monitoring wells, MW-63B and 65B, located about 500 feet downgradient of the landfill exhibited nickel levels above the MCL. Other metallic constituents in these wells were either below the instrument detection limit or below the MCLs.

Organics. Several organic compounds were detected in the USZ groundwater at various concentration levels throughout the site (Table 5-4). Some of these compounds were detected only once out of the five times a well was sampled, while others were more frequently detected. Of the detected compounds, the following are considered to be predominant constituents due to their frequency of detection and concentration levels: 1,1-dichloroethane, cis-1,2-dichloroethene, 1,2-dichloroethene, 1,2-dichlorobenzene, benzene, bis(2-chloroethyl)ether, bis(2-ethylhexyl)phthalate, dichlorofluoromethane, di-n-octyl phthalate, methylene chloride, tetrachloroethene, trichloroethene, and vinyl chloride.

Out of the detected compounds, 1,2-dichloroethene, benzene, tetrachloroethene, trichloroethene, and vinyl chloride are considered to be significant contaminants. These compounds have been identified as significant contaminants because they were detected at concentrations above the MCLs and/or SWMU CALs. 1,2-Dichloroethane was detected in monitoring well MW-31, located within the landfill area, at a concentration level of 7 μg/L, above the MCL of 5 μg/L. Benzene was detected in five monitoring wells (MW-12, MW-30, MW-53, MW-56B, and MW-66B) at concentrations above the MCL value of 5 μg/L. The maximum concentration was detected in a sample collected from monitoring well MW-56B at 84 μg/L, about 16 times the MCL. This well is located on the east side of the landfill area. Tetrachloroethene was detected above the MCL value of 5 μg/L in only one monitoring well, MW-39. The concentration of tetrachloroethene in this well was up to 11 μg/L. Trichloroethene was detected in four wells at concentration levels above the MCL level of 5 μg/L. The highest concentration was in monitoring MW-39 located within the landfill area. The maximum concentration of trichloroethene in this well was at 24 μg/L, about 5 times above the MCL. Other wells that exhibited trichloroethene levels above the MCL include MW-12, MW-56B, and MW-57B. Figure 5-1 depicts the distribution of trichloroethylene in the USZ for the sampling conducted in 1994. The figure shows high concentrations of trichloroethylene mainly in two monitoring wells, MW-39 and MW-56B. Analytical data from previous sampling of these two wells have consistently been above the action level (Table 5-4).

Vinyl chloride was detected in several wells at concentration levels above the MCL value of 2 μg/L. The highest concentration was in monitoring well MW-39, located within the landfill area, on the south side. The concentration of vinyl chloride in this well was at 130 μg/L, 65 times above the MCL. Other monitoring wells having vinyl chloride levels above the MCL include: MW-12 at 63 μg/L, 31 times the MCL; MW-31 at maximum concentration of 15 μg/L, 6 times the MCL; MW-37 at 4 μg/L, 2 times the MCL; and MW-57B at 10 μg/L, 5 times the MCL. Cis-1,2-dichloroethene was detected in only one monitoring well (MW-39) above the SWMU CAL value of 70 μg/L. The concentration of cis-1,2-dichloroethene in this well was at 180 μg/L, about 2 times the SWMU CAL. Bis(2-chloroethyl)ether was detected in one monitoring well, MW-37, and showed a maximum concentration of 96 μg/L, considerably above the SWMU CAL value of 0.03 μg/L. Bis(ethylhexyl)phthalate was detected in several monitoring wells at levels higher than the SWMU CAL. The highest concentration was detected in MW-37 at 24,000 μg/L, 8,000 times the SWMU CAL value of 3 μg/L. Other monitoring wells that exhibited concentration levels above the CAL include: MW-12 at 230 μg/L, MW-30 at 10 μg/L, MW-31 at 10 μg/L, MW-39 at 14 μg/L, MW-53 at 20 μg/L, MW-56B at 4 μg/L, MW-55B at 8 μg/L, and MW-67B at 36 μg/L. Methylene chloride was detected in several monitoring wells, with the highest concentration levels being from well MW-57B at 120 μg/L, 24 times the CAL value of 5 μg/L. Other monitoring wells that exhibited levels of methylene chloride above the CAL include: MW-12, MW-30, MW-39, MW-53, MW-55B, and MW-56B.

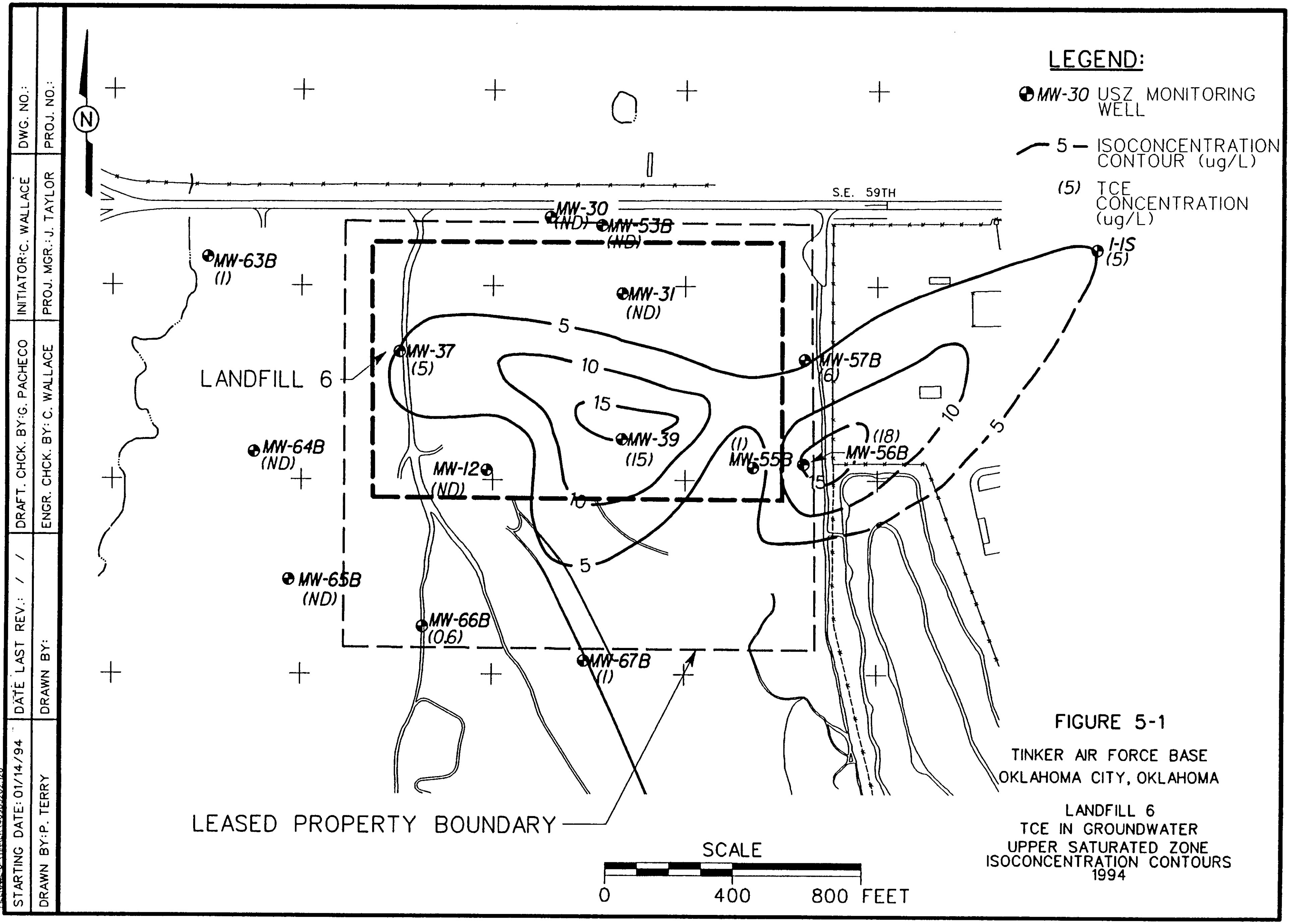

FIGURE 5-1

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 6
TCE IN GROUNDWATER
UPPER SATURATED ZONE
ISOCONCENTRATION CONTOURS
1994

Lower Saturated Zone

Metals. Samples from 13 monitoring wells were analyzed during the period from 1986 to 1992 in order to determine the chemical quality of the LSZ at Landfill 6 site. Some of the wells did not produce sufficient water to be sampled during this period; as a result they were sampled only once or twice. Metals detected at significant concentrations include barium, cadmium, chromium, lead, and nickel. Barium concentrations exceeded the MCL value of 2,000 µg/L in two samples collected from monitoring wells, MW-26 and MW-38. As previously discussed, higher concentrations of barium could be caused by migration of groundwater through the sandstone stratum (Oklahoma Rose Rock) containing barium sulfate, which is common in the area. Cadmium concentration exceeded the MCL of 5 µg/L in four samples collected in monitoring wells MW-26, MW-28, and MW-38. Chromium concentration exceeded the MCL of 100 µg/L in two samples collected from monitoring wells MW-26 and MW- 63A. Lead concentration exceeded the MCL value of 15 µg/L in 12 samples collected from several monitoring wells. The highest concentration of 280 µg/L was in a sample collected from monitoring well MW-26. Nickel concentration exceeded the MCL value of 100 µg/L in five samples. The highest concentration of 2,350 µg/L was in a sample collected from monitoring well MW-66A.

Organics. VOCs and SVOCs were also detected sporadically throughout the site in the LSZ. The LSZ contains much lower concentrations of VOCs and SVOCs than the USZ. Methylene chloride concentrations exceeded the SWMU CAL of 5 µg/L in ten samples. The concentrations were as much as 18 µg/L in monitoring well MW 63A. Several sample blanks contained low concentrations of methylene chloride, which is a common laboratory contaminant. The presence of methylene chloride is not considered significant. Trichloroethylene was detected above the MCL value of 5 µg/L in eight samples collected from several wells. The highest concentration was 41 µg/L detected in monitoring well MW-38. This well is located in the southern part of the landfill area. Benzene concentrations exceeded the MCL value of 5 µg/L in eight samples. The maximum concentration of 89 µg/L was detected in monitoring well MW-56A. This well is located on the southeast corner of the landfill area.

Bis(ethylhexyl)phthalate was detected in 12 samples at concentrations exceeding the SWMU CAL of 3 µg/L. The maximum concentration of 100 µg/L was detected in monitoring well MW-57A, located on the east side of the land fill area.

A summary of the primary chemical constituents with the frequency of occurrence is listed in Table 5-12.

5.3.2 Focused RI Results

The focused RI activities (CDM, 1993) were performed to determine if a source or sources upgradient of Landfill 6 could be responsible for elevated levels of chloride, sulfate, and TDS found within the boundary of the landfill. A general assessment of these analytes and groundwater flow patterns in the USZ concluded that hypothesized sources located east-northeast of the landfill were not responsible for elevated concentrations of chloride in groundwater from the southwest corner of the landfill. Analytical results are presented in Table 5-6.

Lower sulfate levels east-northeast of the landfill indicated the source of elevated sulfate concentrations in groundwater from within the southeast boundary of the landfill did not come from the northeast. It is possible that the elevated sulfate levels within the landfill could be due, in part, from a common source located south-southeast of both wells or from local variations in mineralogy of the aquifer materials. However, it cannot be specifically determined whether the high sulfate levels in these areas are related.

Elevated chloride and TDS concentrations were found in the deep wells underneath the southeast corner of the landfill. These higher concentrations imply vertical migration from the upper to the lower aquifer in areas underlying the southeast corner of the landfill. It appears that the landfill is the source of elevated levels for these ions in the lower aquifer. Gaps, minute cracks, or fissures may be present in the aquitard separating the two aquifers. These pathways, or other conduits, could serve as migrating routes for ionic constituents or other contaminants from the landfill to the lower aquifer.

Chloride concentrations in samples taken from wells located in the USZ north and east of the landfill were much lower than concentrations in samples from wells located in the southwest corner of the landfill. The source of elevated chloride in the landfill area is most likely waste material buried within the landfill trenches.

The results of the focused RI lead to the following conclusions:

- USZ groundwater within the landfill originates from the east-southeast and east-northeast direction of the landfill. LSZ groundwater underlying the landfill originates from the east-northeast direction of the landfill.

Table 5-12

Frequency of Chemical Constituents in 1986 through 1988, 1989, 1991, and 1992 LSZ Groundwater Samples SWMU-1, Landfill 6, Tinker AFB

Compound	No. Detected/ No. Sampled	Range (µg/L)	Average Concentration µg/L)	Location of Maximum
Metals				
Arsenic	31/45	1-12	3.3	56A
Barium	42/45	51-19000	1046.3	26
Cadmium	5/45	5-15	10.4	26
Chromium	18/45	5.5-590	66.1	63A
Mercury	2/45	0.12	0.12	38
Lead	16/45	1.0B-280	45.9	26
Nickel	14/45	9.8B-2350	247.9	66A
Selenium	15/45	0.4-3.4	1.5	63A
Zinc	28/45	10-220	74	26
Volatiles				
Methylene choride	22/45	0.6-18.0B	6.3	63A
Acetone	2/45	24-720	372	38
Trichloroethene	16/45	1.0-41	10.0	38
Benzene	12/45	1.0-89E	21.1	56A
Toluene	9/45	0.5-17	2.8	38
Semivolatiles				
1,4-Dichlorobenzene	3/45	0.5-45	15.5	36
Bis(2-ethylhexyl)phthalate	15/45	2.0J-100.0B	24.5	57A
Di-n-octyl phthalate	10/45	0.8J-13	5.1	38

- Chloride and TDS concentrations in groundwater northeast and east of the landfill are lower than those found at the landfill. Therefore, it is unlikely that the source of elevated levels of these constituents at the landfill originated from the northeast and east directions.

- Elevated levels of chloride and TDS in the LSZ underlying the landfill seem to be a product of vertical migration from these landfill constituents.

- The similarities between both sets of data indicate that the data taken during the first sampling effort were probably valid. However, the completeness of the second data set gives defensibility to the RI because the data can be considered quantitative.

5.3.3 Groundwater Monitoring Program

Thirteen monitoring wells around Landfill 6 were sampled under the 1994 long term groundwater monitoring program. Of interest are the five monitoring wells (MW-63, MW-64, MW-65, MW-66, and MW-67) located on the downgradient of Landfill 6. Most of the target analytes in these wells were below the detection limit. Some of the monitoring wells in the USZ exhibited isolated hits of the constituents (above the action levels) of concern. Monitoring wells 63B and 67B had concentration levels of nickel at 719 μg/L and 105 μg/L, respectively, above the MCL of 100 μg/L.

The presence of constituents of concern above the action levels in the LSZ was limited to cadmium, chromium, and nickel. Except for monitoring well MW-66A, none of the other wells in the LSZ exhibited concentrations of the constituents of concern above the MCLs or SWMU CALs. Monitoring well MW-66A showed concentrations of cadmium, chromium, and nickel to be above their respective MCLs. Chromium in this well was at a maximum concentration of 1,207 μg/L, while nickel was in highest concentration of 2,100 μg/L. The high levels of the constituents of concern in this well is attributed to leaching of these constituents from the turbid water upon acidification of the unfiltered sample. The turbidity was elevated in this sample as the small volume of water in the well at the time of sampling precluded adequate purging of the well.

Trichloroethylene, bis(2-ethylhexyl)phthalate, and dimethyl phthalate were some of the organic compounds detected in the downgradient wells at significant concentrations during the 1994 sampling. Bis(2-ethyhexyl)phthalate was the only organic compound detected above the action level in the USZ groundwater. Except for well MW-63B, all the downgradient monitoring wells exhibited concentrations of bis(2-ethylhexyl)phthalate above the action level.

The maximum concentration was 14 μg/L, detected in a sample from MW-64B. Trichloroethylene was detected below the action level in the downgradient wells of the USZ.

Groundwater samples from the LSZ exhibited the presence of trichloroethylene, dimethyl phthalate, and bis(2-ethylhexyl)phthalate at relatively high concentration. Trichloroethylene and bis(2-ethylhexyl)phthalate were above their respective action levels (MCLs and SWMU CALs). There is no action level for dimethyl phthalate. The highest concentration of trichloroethylene was in well MW-66A at 27 μg/L, while that of bis(2-ethylhexyl)phthalate was in monitoring well MW-64A at 27 μg/L.

Comparison of the 1994 data with the previous analytical data shows both an increase and a decrease in concentration of the certain constituents of concern in the downgradient wells, but no clear trends are evident. However, some of the downgradient wells, MW-63B, MW-64A, MW-64B, MW-65B, MW-66A, MW-66B, and MW-67B show signs of contamination from the landfill.

5.4 Sediment Characterization

Environmental quality of the sediment in nearby streams was determined by the chemical analysis of six stream sediment samples. Results are given in the USACE 1993 RI report.

Arsenic, barium, lead, nickel, selenium, and zinc were detected in all of the sediment samples. Except for selenium, all the detected metallic constituents were below the background concentration levels. Cadmium was detected near the detection limit in only two samples, while it was below detection in the remaining four samples. Selenium was detected above the background concentration in all the samples. The range of concentrations for selenium was 6 to 30 mg/kg.

Methylene chloride and acetone were detected in samples taken from Elm Creek to the west. Samples SS-1, SS-2, SS-3, had methylene chloride concentrations of 8, 12, and 8 μg/kg, respectively. Acetone was detected in sample SS-1 with a concentration of 28 μg/kg. Table 5-13 contains the frequency of occurrence of each constituent, the maximum concentration, and the location of the maximum concentration.

Table 5-13

Frequency of Chemical Constituents in Stream Sediments SWMU-1, Landfill 6, Tinker AFB

Volatiles (µg/kg)	No. detected/ No. sampled	Range (µg/kg)	Average Concentration (µg/kg)	Sample No.
Methylene chloride	3/6	<5-12	6.1	SS-2
Acetone	1/6	<12 - 28	<12	SS-1
Metals (mg/kg)	**Frequency**	**Range mg/kg**	**Average Concentration mg/kg**	**Sample No.**
Arsenic	6/6	1.5 - 2.7	2.2	SS-6
Barium	6/6	110 - 330	225	SS-1
Cadmium	2/6	<0.5 - 0.69	<0.5	SS-2
Chromium	5/6	<5 - 24	10.4	SS-2
Lead	6/6	4.9 - 13	9.7	SS-3
Nickel	6/6	4.8 - 12	8.1	SS-2
Selenium	6/6	6 - 30	19.6	SS-4
Zinc	6/6	6.5 - 13	10.4	SS-1, SS-2

6.0 Potential Receptors

A specific potential human and ecological receptor search has not been performed for Landfill 6. Data are available in the form of chemical analysis of soils, groundwater, and sediments; current and future uses of these media; and ecologic and demographic information necessary to initiate a potential receptors search. The following sections describe the data available to begin identification of potential receptors.

6.1 Human Receptors

Tinker AFB is situated on a relatively flat expanse of grassland. Prior to the development of the Base, the area was characterized by large tracts of agricultural land. The Base currently occupies approximately 5,000 acres of semi-improved and unimproved grounds that are used for the airfield, golf course, housing area, offices, shops, and other uses characteristic of military installations.

The Garber-Wellington aquifer, which underlies Tinker AFB, is the single most important source of potable groundwater in the Oklahoma City area. The recharge area for the Garber-Wellington aquifer covers the eastern half of Oklahoma County, including Tinker AFB. Approximately 75 percent of the Base's water supply is obtained from production wells pumping from this aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by municipal distribution systems also depend on the Garber-Wellington aquifer. Communities, such as Oklahoma City, presently depending upon surface water supplies also maintain a well system drilled into this aquifer as a standby source of water in the event of drought. Lake Stanley Draper, a local surface water supply reservoir with a small portion of its drainage basin within the boundaries of Tinker AFB, serves a significant recreational function as well.

In 1989, approximately 26,000 military and civilian personnel worked at Tinker AFB. Of these, approximately 2,722 personnel occupied on-Base housing, which consisted of 530 family housing units and seven dormitories. At that time, 1,262 of these residents were children. Military personnel and their families who reside on Base represent the nearest receptors to releases from Tinker AFB.

The current land use at and near the Base is not expected to change because the facilities have decades of useful life remaining and the Base has an important and continuing mission.

However, other future land use scenarios and any human receptors associated with those scenarios may need to be considered.

6.2 Ecological Receptors

Tinker AFB lies within a grassland ecosystem, which is typically composed of grasses, forbes, and riparian (i.e., trees, shrubs, and vines associated with water courses) vegetation. This ecosystem has generally experienced fragmentation and disturbances as result of urbanization and industrialization at and near the Base. While no threatened or endangered plant species occur on the Base, the Oklahoma penstemon (*Penstemon oklahomensis*), identified as a rare plant under the Oklahoma Natural Heritage Inventory Program, thrives in several locations on Base. Tinker AFB policy considers rare species as if they were threatened or endangered and provides the same level of protection for these species.

In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base. However, one specie found on the Base, the Texas horned lizard (*Phrynosoma cornutum*), is a Federal Category 2 candidate specie and under review for consideration to be listed as threatened or endangered. Air Force policy (AFR 126-1) considers candidate species as threatened or endangered and provides the same level of protection.

The Oklahoma Department of Wildlife Conservation also lists several species within the state as Species of Special Concern. Information on these species suggests declining populations but information is inadequate to support listing, and additional monitoring of populations is needed to determine the species status. These species also receive protection by Tinker AFB as threatened or endangered species. Of these species, the Swainson's hawk (*Buteo swainsoni*) and the burrowing owl (*Athene cunicularia*) have been sighted on Tinker AFB. The Swainson hawk, a summer visitor and prairie/meadow inhabitant, has been encountered Basewide. The burrowing owl has been known to inhabit the Air Field at the Base.

7.0 Action Levels

An "action level" is defined by EPA in proposed rule 40 CFR 264.521 (55 FR 30798; 7/27/90), "Corrective Action for Solid Waste Management Units (SWMU) at Hazardous Waste Management Facilities," as a health- and environment-based level, determined by EPA to be an indicator for protection of human health and the environment. In the preamble to this proposed rule, the focus of the RFI phase is defined as "characterizing the actual environmental problems at the facilities." As part of this characterization, a comparison of the contaminant concentrations to certain action levels should be made to determine if a significant release of hazardous constituents has occurred. This comparison is then used to determine if further action or corrective measures are required for a SWMU or an AOC. The preamble to the proposed rule states that the concept of action levels was introduced because of the need for "a trigger that will indicate the need for a Corrective Measures Study (CMS) and below which a CMS would not ordinarily be required" (55 FR 30798; 7/27/90). If constituent concentrations exceed certain action levels at a SWMU or an AOC, further action or a CMS may be warranted; if constituent concentrations are below action levels, a finding of no further action may be warranted. This chapter of the report presents the initial analytical data as compared to certain potential action levels.

Action levels are concentrations of contaminants at or below which exposure to humans or the environment should not produce acute or chronic effects.

The action level information is presented in this chapter so that a constituent concentration at a sample location can be compared with its potential action level. Only constituents identified in the analysis are listed in the SWMU-1, Landfill 6 table. Table 7-1 shows the action levels for soil, water, and air as published in federal or state regulations, policies, guidance documents, or proposed rules.

The action levels listed in Table 7-1 are:

- ***SWMU Corrective Action Levels (CAL)*** - The first set of action levels provided in the table are those taken from the proposed rule (40 CFR 264.521) and provided as Appendix A to the rule as "Examples of Concentrations Meeting Criteria for Action Levels." These levels are health-risk based and are provided

Table 7-1

Action Levels
SWMU 1, Landfill 6, Tinker AFB

(Page 1 of 2)

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air ($\mu g/m^3$)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air ($\mu g/m^3$)	WQS[e] Water (mg/L)
Organics							
1,2-Dichlorobenzene				0.6			
1,2-Dichloroethane	8.0		0.04	0.005			
1,2-Dichloropropane				0.005			
1,2,4-Trichlorobenzene	2000	0.7	10	0.07			
1,3-Dichlorobenzene				0.6			
1,4-Dichlorobenzene				0.075			
Acetone	8000	4.0					
Benzene				0.005			0.714
Bis(2-chloroethyl)ether	0.6	3.0×10^{-5}	0.003				
Bis(2-ethylhexyl)phthalate	50	0.003		0.006			
Chlorobenzene	2000	0.7	20	0.1			
Cis-1,2-dichloroethene	8.0		0.04	0.07			
Di-n-octyl phthalate							
Dichlorodifluoromethane	20000	7.0	200				
Diethyl phthalate	60,000	30					
Ethyl benzene	8000	4.0		0.7			28.720
Methylene chloride	90	0.005	0.3	0.005			
n-Nitrosodipropylamine	0.1	5.00×10^{-6}					
Phenol	50,000	20					4615
Tetrachloroethene	10	0.0007	1.0	0.005			
Toluene	20,000	10	7000	1.0			301.9
Trans-1-2-dichloroethene	8		0.04	0.1			
Trichloroethene	60			0.005			

Table 7-1

(Page 2 of 2)

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air ($\mu g/m^3$)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air ($\mu g/m^3$)	WQS[e] Water (mg/L)
Organics (Continued)							
Vinyl chloride				0.002			
Xylenes (total)	2.00×10^5	70	1000	10.0			
Metals							
Antimony	30	0.01		0.006			
Arsenic	80		7.00×10^{-5}	0.05	21		0.0014
Cadmium	40		0.0006	0.005			0.084
Chromium VI	400		9.0×10^{-5}				
Chromium				0.1	110		3.365
Copper				1.3[f]	59		
Cyanide	2000	0.7		0.2			
Lead				0.015[f]	27	1.5[g]	0.025
Mercury	20			0.002			0.0006
Nickel	2000	0.7		0.1	61		4.583
Selenium				0.05	1.2		
Silver	200						64.62
Zinc					79		

[a]CAL - Corrective Action Levels
[b]MCL - Maximum Contaminant Levels
[c]USGS - United States Geological Survey
[d]NAAQS - National Ambient Air Quality Standards
[e]WQS - Water Quality Standards
[f]Action Level at the Tap
[g]3 Month Average

as specific examples of levels below which corrective action would not be required.

- ***Maximum Contaminant Levels (MCL)*** **-** These values are provided from 40 CFR Subpart G, Sections 141.60 through 0.63 as promulgated under the Safe Drinking Water Act. These levels are designated for water media only.

- ***USGS Background*** **-** These values are provided from the USGS report titled "Elemental Composition of Surficial Materials from Central Oklahoma" (USGS, 1991). These values represent the levels of metals which naturally occur in Central Oklahoma soils.

- ***Background*** **-** These levels are provided where background could be determined. Where available, background concentrations are listed for metals in soil samples taken on site, which were thought to be unaffected by releases from a unit.

- ***National Ambient Air Quality Standards (NAAQS)*** **-** These standards are published in 40 CFR Part 50 under the Clean Air Act and apply to point sources that emit a limited number of constituents to the air. The constituents regulated are nitrogen dioxide, sulphur dioxide, carbon monoxide, lead, ozone, and particulate matter. Currently, it is assumed that none of the SWMUs or AOCs emit these compounds in regulated quantities and no air samples have been taken which would allow for a valid comparison.

- ***Water Quality Standards (WQS)*** **-** The WQS are the standards for surface water quality as established by the State of Oklahoma. These standards apply to point source discharges to surface waters and have been listed for those units adjacent to surface water.

A comparison of site specific data with the action levels revealed that certain compounds in the downgradient wells (chromium, nickel, benzene, bis(2-ethylhexyl)phthalate, and methylene chloride) were detected at concentrations above the action levels. Nickel was above the action level in monitoring wells MW-63B and MW-65B installed in the USZ. Benzene was detected at concentration levels about the action level in monitoring well MW-66B. Samples from monitoring well MW-67B exhibited above action level concentrations of bis(2-ethylhexyl)phthalate. Both wells MW-66B and MW-67B are installed in the USZ.

Groundwater samples from the downgradient wells in the LSZ show the presence of two metallic and one organic compound in concentration levels above the action level. Nickel and methylene chloride were detected in monitoring well MW-63A while chromium was detected in monitoring well MW-66A.

The presence of these constituents in downgradient wells at concentrations exceeding the action level is evidence of migration of contaminants away from the site. Furthermore, this condition warrants the undertaking of corrective measures at the site. Recommendations for conducting corrective measures are given in Chapter 9.0.

8.0 Summary and Conclusions

Landfill 6 has a surface area of approximately 40 acres, of which 25 acres were used for waste disposal. The landfill is located approximately one-half mile east of Tinker AFB, near the intersection of Southeast 59th Street and North Douglas Boulevard. Approximately 500,000 yd^3 of waste materials are estimated to have been deposited in the landfill between 1970 and 1979. The landfill received all solid and liquid wastes, including general refuse, industrial wastes, and sludges from industrial wastewaters. General refuse consisted of items such as paper, lumber, leaves, branches, food, and household wastes. Industrial waste consisted of items such as paint, insecticide, and solvent containers.

Past investigations indicate concentrations of metals above background levels, as well as VOCs and SVOCs. Contaminants appear to be sporadic throughout the site, with no continuous concentrations in any one area.

8.1 Soil Investigation

Trench soil sample concentrations of silver, barium, cadmium, chromium, nickel, lead, and zinc exceeded the background levels. Thirteen organic compounds, found sporadically throughout the landfill site, were detected in trench soil samples. Bis(2-ethylhexyl)phthalate concentrations exceeded the SWMU CAL in one trench soil sample.

8.2 Groundwater Investigation

Trench Water. Several metals, VOCs, and SVOCs were detected in the trench water samples. Concentrations of cadmium, chromium, lead, trans-1,2-dichloroethene, and 1,2-dichloropropane exceeded MCLs, and acetone and methylene chloride concentrations exceeded the SWMU CALs in the trench water.

Upper Saturated Zone. The majority of groundwater contamination in the USZ was found to be in the western portions of the landfill site. The primary metal contaminants were arsenic, barium, cadmium, chromium, lead, and nickel, with barium having the highest frequency of occurrence and concentration. Metals detected above their respective MCLs include: arsenic, cadmium, lead, and nickel.

VOCS and SVOCs were sporadically detected throughout the USZ. Of the detected compounds, 1,2-dichloroethene, benzene, bis(2-ethylhexyl)ether, bis(2-ethylhexyl)phthalate, tetrachloroethene, trichloroethene, and vinyl chloride are considered to be significant contaminants, as they were detected above the MCLs or SWMU CALs.

TOC and chloride also appeared in elevated levels in the USZ. The wells with higher TOC concentrations are located to the west of the landfill trenches.

Lower Saturated Zone. LSZ contaminants also were detected sporadically throughout the site, with the majority of contamination detected in the western portion of the landfill. Primary metal contaminants were found to be barium, cadmium, chromium, lead, and nickel. Nickel concentrations exceeded the SWMU CAL, and cadmium, chromium, lead, and barium concentrations exceeded the MCLs in several samples.

VOCs and SVOCs were also detected sporadically in the LSZ. Methylene chloride, bis(2-ethylhexyl)phthalate, and tetrachloroethene concentrations exceeded the SWMU CALs, and benzene and trichloroethene exceeded the MCLs in several samples.

Sediment. Arsenic, barium, chromium, and selenium were detected in all sediment samples. However, only selenium exhibited concentrations above the background in all the samples. Methylene chloride and acetone were detected in samples taken from Elm Creek to the west. None of the detected constituents were above the SWMU CALs.

Conclusions. The various investigations conducted at Landfill 6 confirmed and concluded that the USZ underneath the site was primarily contaminated with metals and organic constituents leached from the landfill. Aquifer contamination was mainly concentrated in the western part of the landfill as a result of groundwater flow in the westerly direction. The deeper LSZ groundwater was found to be contaminated with both metals and some organic but to a lesser extent as compared to the USZ. The source of contamination in the lower aquifer was attributed to downward migration of the contaminated groundwater from the USZ.

Evaluation of current and previously collected data confirms the previous studies, in that, contaminants have migrated away from the site. The concentration levels of these contaminants in downgradient wells exceeds the action levels. This condition indicates a need for a CMS to be undertaken as soon as possible. Groundwater monitoring also should be continued to keep track of contaminant migration.

9.0 Recommendations

This RFI has been prepared to determine and document whether sufficient investigations at Landfill 6 have been performed to meet the permit requirements. Based on the reviews of previous reports and evaluation of data presented in this report, it is evident that contaminants have migrated away from this site. Some of the downgradient monitoring wells in the USZ and LSZ show signs of contamination with certain compounds having concentration levels above the action levels (MCLs and SWMU CALs). The presence of these constituents in the downgradient wells is significant because it shows that release of material from the Landfill 6 has occurred. However, due to limited data the horizontal and vertical extent of contamination has not been fully evaluated at this site. In view of this, Tinker AFB is currently planning to install 28 additional monitoring wells in the vicinity of Landfill 6 during an expedited groundwater investigation conducted as part of the RFI Phase II Investigation of the site. These wells will be installed upgradient and downgradient of the site and will be completed in the USZ and LSZ to determine the extent of contamination in each zone. Eight of these wells will be installed in deeper sections of the LSZ not previously investigated to establish the vertical extent of contamination. These efforts are part of the CMS to be undertaken for the site. The specific elements of the CMS are presented in the following paragraphs.

Data presented in this report indicate concentrations of certain constituents in downgradient wells exceed the action levels. Consequently, a need for undertaking a CMS of the release from the SWMU is necessary. The CMS will include:

- Installation of groundwater wells in the USZ and LSZ around Landfill 6
- Characterization of groundwater north of Landfill 6
- Verification of presence or absence of off-site contamination in the USZ
- Determination of the source of groundwater contamination north of Landfill 6
- Determination of hydraulic gradient of the LSZ in the vicinity of Landfill 6.

The main objective for the CMS is to provide sufficient data necessary for developing a corrective action plan (CAP) to remediate the release from the site. The CAP will involve identifying potential remedial alternatives that will:

- Prevent further migration of the groundwater plume.

- Remediate or stabilize the source of groundwater contamination north of Landfill 6.

It is therefore recommended that:

- Implement the expedited groundwater investigation.

- Conduct a CMS as soon as possible to remediate the release of the contaminants from the landfill.

- Continue monitoring groundwater in the downgradient wells, MW-63, MW-64, MW-65, MW-66, and MW-67 to keep track of contaminant migration while the CMS is underway.

In addition, to fully evaluate the extent of soil contamination at this site it is recommended that site-specific soil background samples be collected during the Phase II RFI. This additional information along with the USGS background values should be used in the Phase II report to distinguish site-related from background concentrations in a statistically significant manner. During the development of the Phase II RFI work plan, the number of background samples to be collected, the location of the soil borings, and the soil analysis to be performed on the samples should be determined for EPA approval.

10.0 References

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Final Report
Phase I RCRA Facility Investigation for Appendix I Sites
VOLUME VII
SWMU-2, Landfill No. 5

Department of the Air Force
Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma

September 1994

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List of Acronyms

AFB	Air Force Base
AOC	area of concern
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/s	centimeters per second
DERP	Defense Environmental Restoration Program
DOD	U.S. Department of Defense
EID	Engineering Installation Division
EPA	U.S. Environmental Protection Agency
ES	Engineering Science
ft/ft	foot per foot
HELP	Hydrologic Evaluation of Landfill Performance (Model)
HSWA	Hazardous and Solid Waste Amendment
IRP	Installation Restoration Program
LSZ	lower saturated zone
MCL	maximum concentration level
msl	mean sea level
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
mg/L	milligrams per liter
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPL	National Priorities List
PA/SI	preliminary assessment/site investigation
PCB	polychlorinated biphenyl
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
RFI	RCRA Facility Investigation
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TSD	treatment, storage, and disposal (facility)
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers

USC	U.S. Code
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USZ	upper saturated zone
UWBZ	upper water bearing zone
VOC	volatile organic compounds

Executive Summary

This report provides a summary of the various investigations that have been conducted at solid waste management unit (SWMU)-2, Landfill No. 5 (Landfill 5), Tinker Air Force Base (AFB), Oklahoma. The report has been prepared to determine and document whether sufficient investigations at Landfill 5 have been performed to meet regulatory requirements. Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County. The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. The Base encompasses approximately 5,000 acres.

Background. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon^{TM}, jet fuels, and radium paints.

In 1984, Congress amended the Resource Conservation and Recovery Act (RCRA) with the Hazardous and Solid Waste Amendments (HSWA), which allow the U.S. Environmental Protection Agency (EPA) to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or constituents from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989, Tinker AFB submitted its Part B permit application for renewal of its operating RCRA hazardous waste storage facility permit. The final RCRA HSWA permit, issued on July 1, 1991, requires Tinker AFB to investigate all SWMUs and areas of concern (AOC) and to perform corrective action at those identified as posing a threat to human health or the environment. The permit specifies that a RCRA Facility Investigation (RFI) be conducted for 43 identified SWMUs and two AOCs on the Base. This document has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 5.

Source Description. Landfill 5 was in operation from 1968 to 1970. During its operational period the landfill received approximately 75,000 cubic yards of waste. Waste disposed of in the landfill consisted of general refuse with small quantities of industrial waste. Presently the landfill is not in operation and is covered with soil and vegetation.

Site Investigations. The initial phase investigations for Landfill 5 were conducted by Engineering Science (ES, 1982). The investigations consisted of a record search and preliminary assessment of past waste disposal practices and contamination potential at the site. During the investigations, three monitoring wells were installed at the site and the site was identified as an area that had moderate potential for contaminant migration.

Radian Corporation (Radian) in 1983 conducted phase II field investigations to determine if any environmental contamination resulted from waste disposal practices, to estimate the magnitude and extent of contamination, and recommend additional work to identify the extent and direction of movement of the contaminants. One additional well was installed at the site.

Remedial investigation (RI) activities were conducted by the U.S. Army Corps of Engineers (USACE) from 1986 to 1990. The RI activities included a record search of waste types present at the landfill, drilling and sampling of waste materials and subsurface soil and rock, and installation and sampling of groundwater monitoring wells. Four borings were drilled into the landfill trenches and solid waste was sampled. In addition, five monitoring wells were installed during RI investigations to monitor groundwater at the site.

During drilling activities, solid waste was encountered from 3.0 to 7.5 feet below the surface and was 16 to 17 feet in thickness. Solid waste samples taken from the landfill trenches and the seep location contained low to moderate concentrations of heavy metals and organic compounds.

Groundwater at the site was found to occur in three zones: (1) the leachate in the landfill trenches, (2) the upper saturated zone (USZ), and (3) the lower saturated zone (LSZ). A total of nine monitoring wells were installed at the landfill. Five wells monitored the USZ and four wells monitored the LSZ. The chemical quality of groundwater was determined by yearly sampling of existing wells at the site from 1986 through 1992. In addition, two water samples were collected from the water contained in the trench borings. Contaminants detected in landfill trench water included cadmium, lead, and, nickel and organic compounds which were primarily ketones and fuel-related compounds. Contaminants found in the USZ and LSZ included heavy metals and organic compounds which were primarily halogenated solvents.

Contamination was found in the solid wastes and leachate in the landfill as well as the USZ and the LSZ. An 18-inch-thick, compacted clay cap with 12 inches of topsoil was placed over Landfill 5 in August 1990 to minimize any infiltration and spread of contaminants as an interim remedial action. In addition, a nearby water supply well (well 28) was plugged and two wells (MW-8 and MW-8A) were abandoned to make way for the E-6A TACAMO II Naval Project.

Recommendations. The Landfill 5 RI report by USACE concluded that the data collected during RI activities were insufficient to make a conclusion regarding the potential contribution by Landfill 5 to contamination in the USZ and LSZ and potential contamination to surface water. Therefore, the following is recommended to enable full definition of the vertical and horizontal extent of contamination at the landfill and to fully meet EPA Hazardous Waste Management Permit requirements for the site:

- Evaluate the effectiveness of the cap to minimize infiltration and appropriately channel surface water runoff.

- Evaluate the areal extent of the cap and determine the need for soil sample locations outside the limits of the cap (possibly up to six soil samples collected from all sides of the cap and analyzed for metals, volatile organic compounds [VOC], and semivolatile organic compounds [SVOC]). The soil analytical results are necessary to define the extent of soil contamination, if any, in the immediate vicinity of the cap.

- Collect site-specific soil samples to use with the USGS soils data to distinguish site-related from background concentrations in a statistically significant manner.

- Evaluate both soil and groundwater analytical data with respect to human health and ecological impact (perform a specific potential human and ecological receptor search).

- Evaluate the most recent groundwater data (November 1993) with sufficient graphical presentations to determine the current site conditions and to provide recommendations for specific monitoring well locations which may be necessary to further define extent of groundwater contamination.

- Install four downgradient and one upgradient USZ/LSZ monitoring well clusters. In addition, one upgradient cluster and two downgradient clusters will include deeper wells completed at approximately 150 feet to monitor deeper sections of the LSZ. All monitoring wells will have 10-foot screens unless geological conditions require shorter screens.

- Continue groundwater sampling to monitor contaminant migration and site conditions.

1.0 Introduction

1.1 Purpose and Scope

This document has been prepared in response to a request from the Department of Air Force. Tinker Air Force Base (AFB), Oklahoma for a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Summary Report for solid waste management unit (SWMU)-2, Landfill No. 5 (Landfill 5).

The objective of this RFI Summary Report is to provide Tinker AFB with one comprehensive report that summarizes the various investigations that have occurred at Landfill 5 since the first environmental investigation was conducted on Base in 1981. The purpose of this comprehensive summary document is to:

- Characterize the site (Environmental Setting).
- Define the source (Source Characterization), if any.
- Define the degree and extent of contamination (Contamination Characterization).
- Identify actual or potential receptors.
- Identify all action levels for the protection of human health and the environment.

Additionally, this document briefly describes the procedures, methods, and results of all previous investigations and remedial actions that relate to Landfill 5, and contaminant releases, including information on the type and extent of contamination at the site, sources and migration pathways, and actual or potential receptors. Where previous investigations, reports, or studies were not comprehensive and did not furnish the information required to determine the nature and extent of contamination, future work that can be conducted to complete the investigation has been recommended.

1.2 Preface

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to address the cleanup of hazardous waste disposal sites across the country. CERCLA gave the president authority to require responsible parties to remediate the sites or to undertake response actions through use of a fund (the Superfund). The president, through Executive Order 12580, delegated the U.S. Environmental Protection Agency (EPA) with the responsibility to investigate and remediate private party hazardous waste disposal sites that created a threat to human health and the environment. The president delegated responsibility for investigation and cleanup of federal facility disposal sites to the various federal agency heads. The Defense Environmental Restoration Program (DERP) was formally

established by Congress in Title 10 U.S. Code (USC) 2701-2707 and 2810. DERP provides centralized management for the cleanup of U.S. Department of Defense (DOD) hazardous waste sites consistent with the provisions of CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations [CFR] 300), and Executive Order 12580. To support the goals of DERP, the Installation Restoration Program (IRP) was developed to identify, investigate, and clean up contamination at installations.

Under the Air Force IRP, Tinker AFB began a Phase I study similar to a preliminary assessment/site investigation (PA/SI) in 1981 (Engineering Science [ES], 1982). This study helped locate 14 sites that needed further investigation. Phase II studies were performed in 1983 (Radian Corporation [Radian], 1985a,b).

In 1986, Congress amended CERCLA through SARA. SARA waived sovereign immunity for federal facilities. This act gave EPA authority to oversee the cleanup of federal facilities and to have the final authority for selecting the remedial action at federal facilities placed on the National Priorities List (NPL) if the EPA and the relevant federal agency cannot concur in the selection. Congress also codified DERP (SARA Section 211), setting up a fund for the DOD to remediate its sites because the Superfund is not available for the cleanup of federal facilities. DERP specifies the type of cleanup responses that the fund can be used to address.

In response to SARA, the DOD realigned its IRP to follow the investigation and cleanup stages of the EPA:

- PA/SI
- Remedial investigation/feasibility study (RI/FS)
- Record of Decision (ROD) for selection of a remedial action
- Remedial design/remedial action.

In 1984, Congress amended RCRA with the Hazardous and Solid Waste Amendments (HSWA), which allow the EPA to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or constituents from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989, Tinker AFB submitted its Part B permit application for renewal of its operating RCRA hazardous waste storage facility permit.

EPA, in the Hazardous Waste Management Permit for Tinker AFB, dated July 1, 1991, identified 43 SWMUs and two areas of concern (AOC) on Tinker AFB that need to be addressed. The permit requires Tinker AFB to investigate all SWMUs and AOCs and to perform corrective action at those identified as posing a threat to human health or the environment. This RFI Summary Report has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 5 and to document all determinations.

1.3 Facility Description

Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County (Figure 1-1) with its approximate geographic center located at 35° 25' latitude and 97° 24' longitude (U.S. Geological Survey [USGS], 1978). The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. An additional area east of the main Base is used by the Engineering Installation Division (EID) and is known as Area D. The Base encompasses approximately 5000 acres. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon™, jet fuels, and radium paints. Wastes that are currently generated are managed at two permitted hazardous waste storage facilities. However, prior to enactment of RCRA, industrial wastes were discharged into unlined landfills and waste pits, streams, sewers, and ponds. Past releases from these landfills, pits, etc., as well as from underground tanks, have occurred. As a result, there are numerous sites of soil, groundwater, and surface water contamination on the Base.

The various reports generated as a result of investigative activities conducted at Landfill 5 have been reviewed and evaluated in terms of the sites' status under RCRA regulations. A summary based on the review of these reports for Landfill 5 is presented in the following chapters and sections. In addition, recommendations for additional work is given at the end of the summary report.

1.4 Site Description

Landfill 5 is located in the south portion of Tinker AFB and is bounded by Tower Road on the west, the taxiway to the south, and Crutcho Creek to the north and east. Landfill 5 is

STARTING DATE: 03/17/94 | DATE LAST REV.: | DRAFT. CHCK. BY:G. PACHECO | INITIATOR: C. WALLACE | DWG. NO.:

DRAWN BY:P.O. TERRY | DRAWN BY: | ENGR. CHCK. BY: C. WALLACE | PROJ. MGR.:J. TAYLOR | PROJ. NO.:

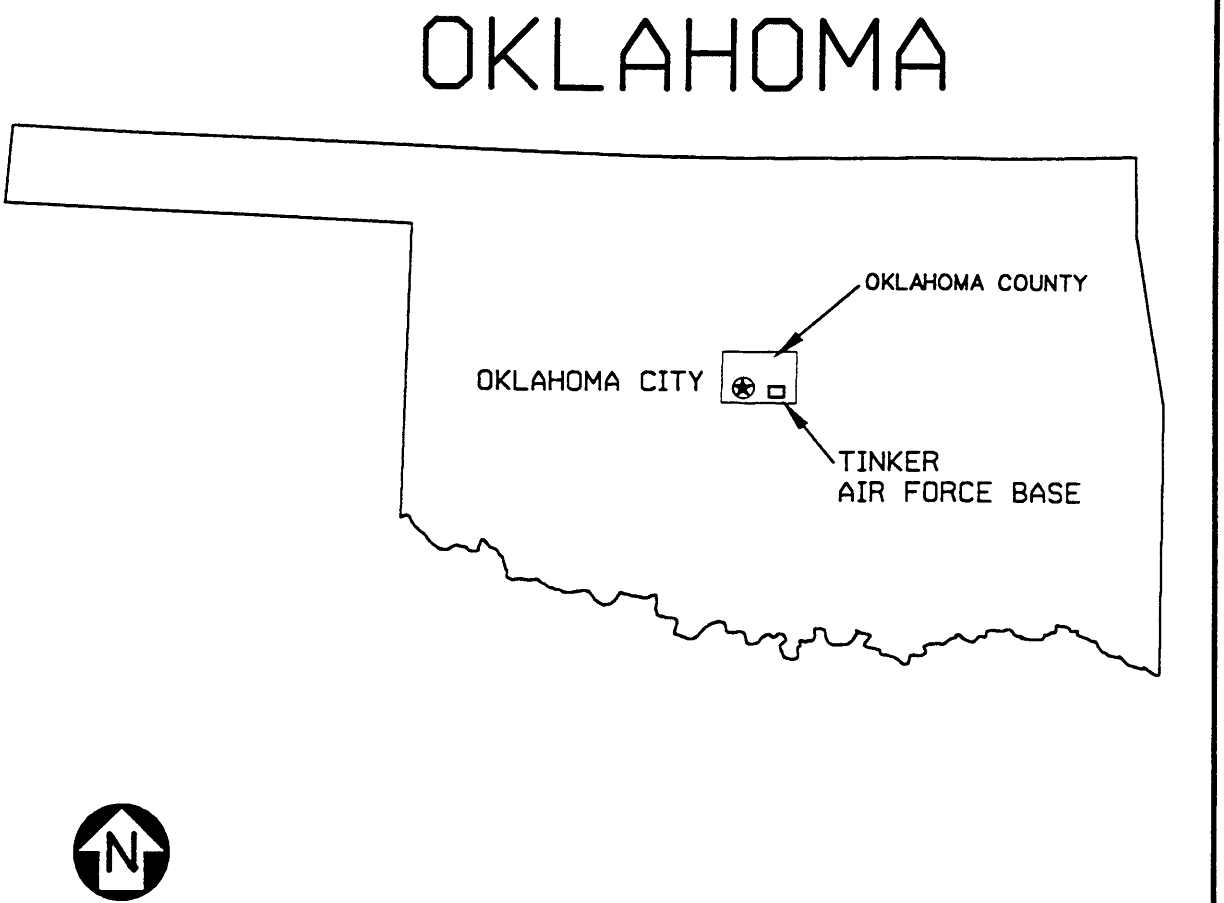

FIGURE 1-1
TINKER AIR FORCE BASE
OKLAHOMA
STATE INDEX MAP

PREPARED FOR
TINKER AFB
OKLAHOMA

3/23/94 POT
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triangular in shape and encompasses an estimated 6 acres. The landfill consists of trenches containing waste that run from northwest to southeast. The trenches are estimated to be 400 feet long, 50 feet wide, and 16 feet deep. A compacted clay and topsoil cap was constructed over the trenched area in August 1990 to minimize infiltration of precipitation. Figure 1-2 shows the location of Landfill 5 relative to the Base and the other landfills.

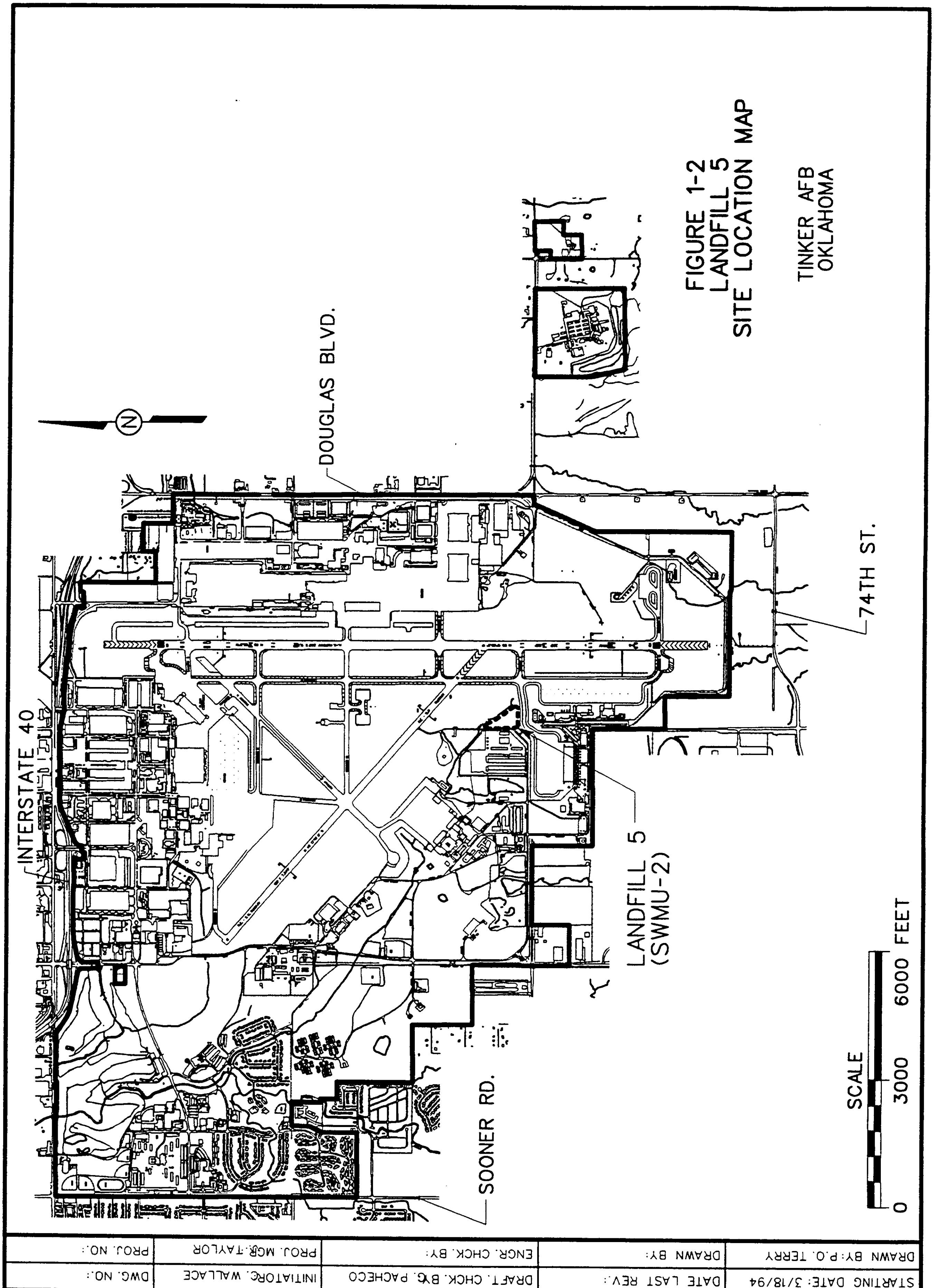

FIGURE 1-2
LANDFILL 5
SITE LOCATION MAP
TINKER AFB
OKLAHOMA
DOUGLAS BLVD.
INTERSTATE 40
74TH ST.
LANDFILL 5
(SWMU-2)
SOONER RD.
SCALE
0
3000
6000 FEET
DRAWN BY: P.O. TERRY
STARTING DATE: 3/18/94
DRAWN BY:
DATE LAST REV.:
ENGR. CHCK. BY:
DRAFT. CHCK. BY: G. PACHECO
PROJ. MGR.: TAYLOR
INITIATOR: C. WALLACE
PROJ. NO.:
DWG. NO.:
FILENAME: G:\TINKER\4098320Z.080

2.0 Background

2.1 Site Operations and History

Tinker AFB was originally known as the Midwest Air Depot and began operations in July 1941. The site was activated March 1942. During World War II the depot was responsible for reconditioning, modifying, and modernizing aircraft, vehicles, and equipment.

General refuse generated from these operations has been disposed of in at least six landfills located on the Base property or on leased land adjacent to the Base. One of these landfills, Landfill 5, is located on the south portion of the Base.

Landfill 5 was in operation from 1968 to 1970 (Radian, 1985a); the landfill encompasses an estimated 6 acres and contains approximately 75,000 cubic yards of waste. Waste disposed of in the landfill consisted of general refuse with small quantities of industrial waste. Presently, the landfill is not in operation and is covered with soil and vegetation.

2.2 Summary of Previous Investigations

Engineering Science, Inc. IRP investigations for Landfill 5 were conducted in two phases during the 1980s. Phase 1 investigations were conducted by ES (ES, 1982) and consisted of a record search and an initial assessment of past waste disposal practices and pollution potential at the landfill. During the investigation, three monitoring wells were installed along Crutcho Creek (Figure 2-1). A small seep was found near the northeast edge of the site along Crutcho Creek. Later, during Phase II investigations, the seep was found to be dry. Landfill 5 was identified as an area that had moderate potential for contaminant migration.

Radian Corporation. The Phase II field investigations were conducted by Radian in 1983 (Radian, 1985 a,b). The investigation was to determine if any environmental contamination resulted from waste disposal practices at Tinker AFB, to estimate the magnitude and extent of contamination, to identify environmental consequences of migrating pollutants, and to recommend additional investigations to identify the extent and direction of movement of the discovered contaminants. The Phase II, Stage 1 report recommended additional subsurface investigations and continued monitoring of wells along Crutcho Creek to determine seasonal variations of water quality. One additional well was installed at the site to monitor the upper water bearing zone (UWBZ).

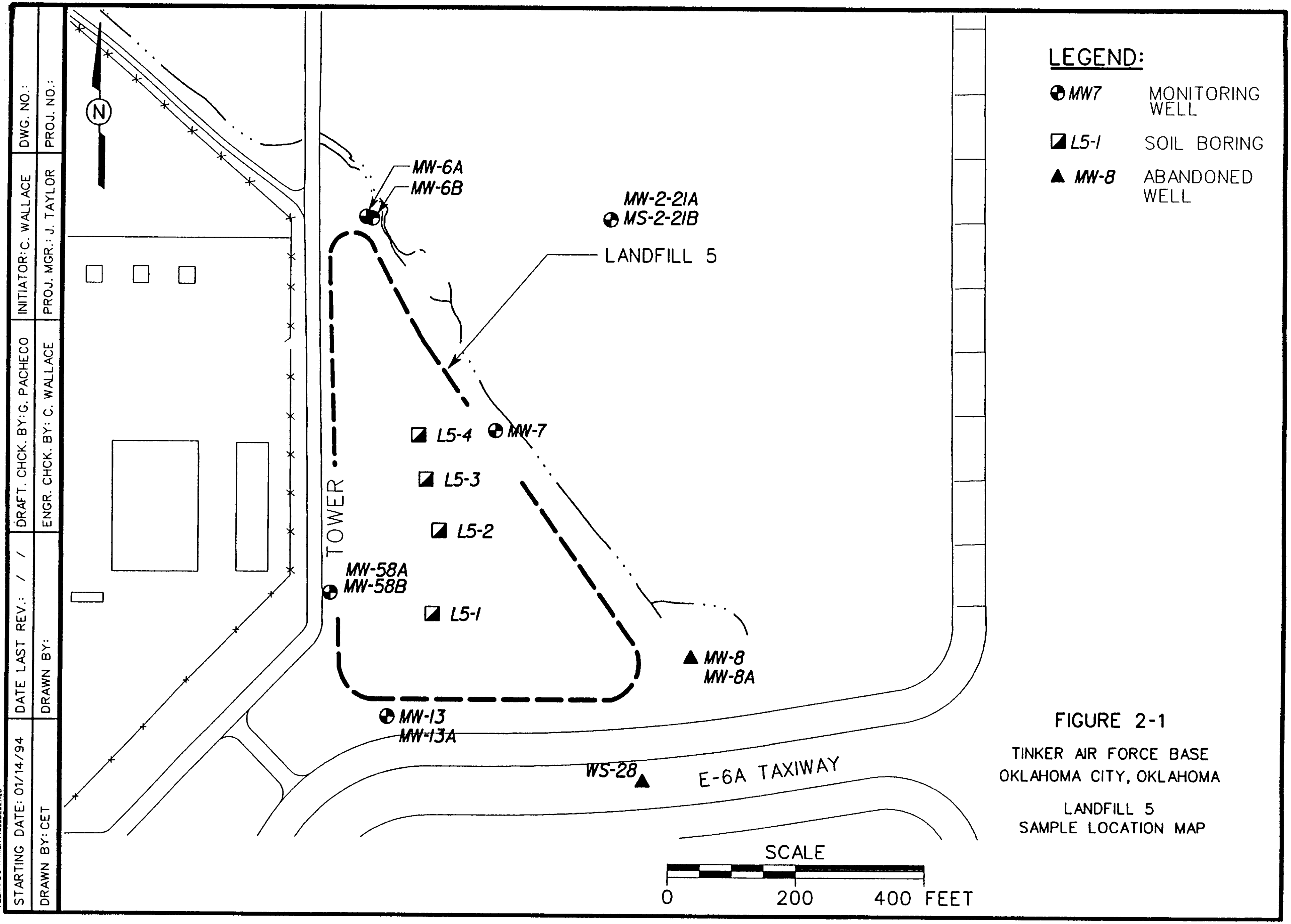

FIGURE 2-1

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 5
SAMPLE LOCATION MAP

U.S. Army Corps of Engineers. The Landfill 5 site was further investigated from September 1986 to 1990 by the U.S. Corps of Engineers (USACE, 1993b). The RIs by the USACE determined the nature and extent of contamination at Landfill 5, the general location and depth of the landfill trenches, and the potential impact of a taxiway under construction south of the landfill. The RIs also developed subsurface information for selection and design of an appropriate remedial action. The RI activities included a records search, drilling and sampling of waste materials and adjacent subsurface soil and rock, and installation and sampling of groundwater monitoring wells. Four borings were drilled into the landfill trenches and the solid waste was sampled. In addition, five monitoring wells were installed, with one well monitoring the UWBZ and four wells monitoring the lower water bearing zone.

Soil and water samples from the trenches and monitoring wells were analyzed for metals, total organic carbon (TOC), chloride, sulfate, cyanide, pH, conductivity, volatile organics, and semivolatile organics. Analytical results indicated organic compounds and metals were detected in the trench water, UWBZ, and lower water bearing zone in the Landfill 5 area. Contaminant concentrations in groundwater were lower in the lower water bearing zone than in the UWBZ.

2.3 Current Regulatory Status

The IRP has been ongoing at Tinker AFB since the early 1980s. IRP studies on the Base were conducted according to IRP guidance, which is essentially the same as EPA's guidance for conducting RI/FSs under CERCLA. All investigation and removal actions have been closely monitored and approved by the EPA.

Since receiving the Hazardous Waste Management Permit on July 1, 1991, many of the IRP sites have come under the jurisdiction of the RCRA permits branch of EPA. As such, they have been identified as SWMUs; however, a large amount of work has already been performed at most of these sites under the IRP. Additional investigation at the SWMUs will be performed under the IRP.

3.0 Environmental Setting

3.1 Topography and Drainage

3.1.1 Topography

Regional/Tinker AFB. The topography of Oklahoma City and surrounding area varies from generally level to gently rolling in appearance. Local relief is primarily the result of dissection by erosional activity or stream channel development. At Oklahoma City, surface elevations are typically in the range of 1,070 to 1,400 feet mean sea level (msl). At Tinker AFB, ground surface elevations vary from 1,190 feet msl near the northwest corner where Crutcho Creek intersects the Base boundary to approximately 1,320 feet msl at Area D (EID).

Site. Landfill 5, located just southwest of Crutcho Creek, is built up 5 to 10 feet above the surrounding land, which slopes gently to the northeast toward Crutcho Creek.

3.1.2 Surface Drainage

Regional/Tinker AFB. Drainage of Tinker AFB land areas is accomplished by overland flow of runoff to diversion structures and then to area surface streams, which flow intermittently. The northeast portion of the Base is drained primarily by unnamed tributaries of Soldier Creek, which is itself a tributary of Crutcho Creek. The north and west sections of the Base, including the main instrument runway, drain to Crutcho Creek, a tributary of the North Canadian River. Two small unnamed intermittent streams crossing installation boundaries south of the main instrument runway generally do not receive significant quantities of Base runoff due to site grading designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

Site. Prior to capping Landfill 5 in August 1990, the surface drained to the north-northeast into Crutcho Creek. Crutcho Creek runs to the northwest. Presently, surface drainage in the vicinity of Landfill 5 is influenced by the compact clay and topsoil cap in place at the site. The cap minimizes the infiltration of water into the landfill trenches and forces rainwater to drain from the landfill area towards Crutcho Creek.

3.2 Geology

3.2.1 Regional/Tinker AFB Geology

Tinker AFB is located within the Central Redbed Plain Section of the Central Lowland physiographic province, which is tectonically stable. No major fault or fracture zones have been mapped near Tinker AFB. The major lithologic units in the area of the Base are relatively flat-lying and have a regional westward dip of about 0.0076 foot per foot (Bingham and Moore, 1975).

Geologic formations that underlie Tinker AFB include, from oldest to youngest, the Wellington Formation, Garber Sandstone, and the Hennessey Group; all are Permian in age.

All geologic units immediately underlying Tinker AFB are sedimentary in origin. The Garber Sandstone and Wellington Formation are commonly referred to as the Garber-Wellington Formation due to strong lithologic similarities. These formations are characterized by fine-grained, calcareously-cemented sandstones interbedded with shale. The Hennessey Group consists of the Fairmont Shale and the Kingman Siltstone. It overlies the Garber-Wellington Formation along the eastern portion of Cleveland and Oklahoma counties. Quaternary alluvium is found in many undisturbed streambeds and channels located within the area.

Stratigraphy. Tinker AFB lies atop a sedimentary rock column composed of strata that ranges in age from Cambrian to Permian above a Precambrian igneous basement. Quaternary alluvium and terrace deposits can be found overlying bedrock in and near present-day stream valleys. At Tinker AFB, Quaternary deposits consist of unconsolidated weathered bedrock, fill material, wind-blown sand, and interfingering lenses of sand, silt, clay, and gravel of fluvial origin. The terrace deposits are exposed where stream valleys have downcut through older strata and have left them topographically above present-day deposits. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

Subsurface (bedrock) geologic units which outcrop at Tinker AFB and are important to understanding groundwater and contaminant concerns at the Base consist of, in descending order, the Hennessey Group, the Garber Sandstone, and the Wellington Formation (Table 3-1). These bedrock units were deposited during the Permian Age (230 to 280 million years ago) and are typical of redbed deposits formed during that period. They are composed of a conformable sequence of sandstones, siltstones, and shales. Individual beds are lenticular and vary in thickness over short horizontal distances. Because lithologies are similar and because

Table 3-1

Major Geologic Units in the Vicinity of Tinker AFB (Modified from Wood and Burton, 1968)

(Page 1 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	PLEISTOCENE AND RECENT	Alluvium	0-70	Unconsolidated and interfingering lenses of sand, silt, clay, and gravel in the flood plains and channels of stream	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines.
		Terrace deposits	0-100	Unconsolidated and interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above the flood plains of the principal streams.	Moderately permeable. Locally above the water table and not saturated. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

Table 3-1

(Page 2 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
PERMIAN	LOWER PERMIAN	Hennessey Group (includes Kingman Siltstone and Fairmont Shale)	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places water contains large amounts of sulfate.
		Garber Sandstone	500±	Deep-red clay to reddish-orange, massive and cross-bedded fine-grained sandstone interbedded and interfingered with red shale and siltstone	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

of a lack of fissiles or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are often informally lumped together as the Garber-Wellington Formation. Together, they are about 900 feet thick at Tinker AFB. The interconnected, lenticular nature of sandstones within the sequence forms complex pathways for groundwater movement.

The surficial geology of the north section of the Base is dominated by the Garber Sandstone, which outcrops across a board area of Oklahoma County. Generally, the Garber outcrop is covered by a veneer of soil and/or alluvium up to 20 feet thick. To the south, the Garber Sandstone is overlain by outcropping strata of the Hennessey Group, including the Kingman Siltstone and the Fairmont Shale (Bingham and Moore, 1975). Drilling information obtained as a result of geotechnical investigations and monitoring well installation confirms the presence of these units.

Depositional Environment. The Permian-age strata presently exposed at the surface in central Oklahoma were deposited along a low-lying north-south oriented coastline. Land features included meandering to braided sediment-loaded streams that flowed generally westward from highlands to the east (ancestral Ozarks). Sand dunes were common, as were cut-off stream segments that rapidly evaporated. The climate was arid and vegetation sparse. Off shore the sea was shallow and deepened gradually to the west. The shoreline's position varied over a wide range. Isolated evaporitic basins frequently formed as the shoreline shifted.

Across Oklahoma, this depositional environment resulted in an interfingering collage of fluviatile and wind-blown sands, clays, shallow marine shales, and evaporite deposits. The overloaded streams and evaporitic basins acted as sumps for heavy metals such as iron, chromium, lead, and barium. Oxidation of iron in the arid climate resulted in the reddish color of many of the sediments. Erosion and chemical breakdown of granitic rocks from the highlands resulted in extensive clay deposits. Evaporite minerals such as anhydrite ($CaSO_4$), barite ($BaSO_4$), and gypsum ($CaSO_4 \cdot 2H_2O$) are common.

Around Tinker AFB, the Hennessey Group represents deposition in a tidal flat environment cut by shallow, narrow channels. The Hennessey Group is comprised predominantly of red shales which contain thin beds of sandstone (less than 10 feet thick) and siltstone. In outcrop, "mudball" conglomerates, burrow surfaces, and dessication cracks are recognized. These units

outcrop over roughly the southern half of the Base, thickening to approximately 70 feet in the southwest from their erosional edge (zero thickness) across the central part of Tinker AFB.

In contrast, the Garber Sandstone and the Wellington Formation around Tinker AFB consist of an irregularly-interbedded system of lenticular sandstones, siltstones, and shales deposited either in meandering streams in the upper reaches of a delta or in a braided stream environment. Outcrop units north of Tinker AFB exhibit many small to medium channels with cut and fill geometries consistent with a stream setting. Sandstones are typically cross-bedded. Individual beds range in thickness from a few inches to approximately 50 feet and appear massive, but thicker units are often formed from a series of "stacked" thinner beds. Geophysical and lithologic well logs indicate that from 65 to 75 percent of the Garber Sandstone and the Wellington Formation are composed of sandstone at Tinker AFB. The percentage of sandstone in the section decreases to the north, south, and west of the Base. These sandstones are typically fine to very fine grained, friable, and poorly cemented. However, where sandstone is cemented by red muds or by secondary carbonate or iron cements, local thin "hard" intervals exist along disconformities at the base of sandstone beds. Shales are described as ranging from clayey to sandy, are generally discontinuous, and range in thickness from a few inches to approximately 40 feet.

Stratigraphic Correlation. Correlation of geologic units is difficult due to the discontinuous nature of the sandstone and shale beds. However, cross-sections (Figure 3-1) demonstrate that two stratigraphic intervals can be correlated over large sections of the Base in the conceptual model. These intervals are represented on geologic cross-sections A-A' and B-B' (Figures 3-2 and 3-3). Section A-A' is roughly a dip section and B-B' is approximately a strike section. The first correlatable interval is marked by the base of the Hennessey Group and the first sandstone at the top of the Garber Sandstone. This interval is mappable over the southern half of Tinker AFB. The second interval consists of a shale zone within the Garber Sandstone which, in places, is comprised of a single shale layer and, in other places, of multiple shale layers. This interval is more continuous than other shale intervals and in cross-sections appears mappable over a large part of the Base. It is extrapolated under the central portion of Tinker AFB where little well controls exists.

Structure. Tinker AFB lies within a tectonically stable area; no major near-surface faults or fracture zones have been mapped near the Base. Most of the consolidated rock units of the Oklahoma City area dip westward at a low angle. A regional dip of 0.0057 to 0.0076 ft/ft in

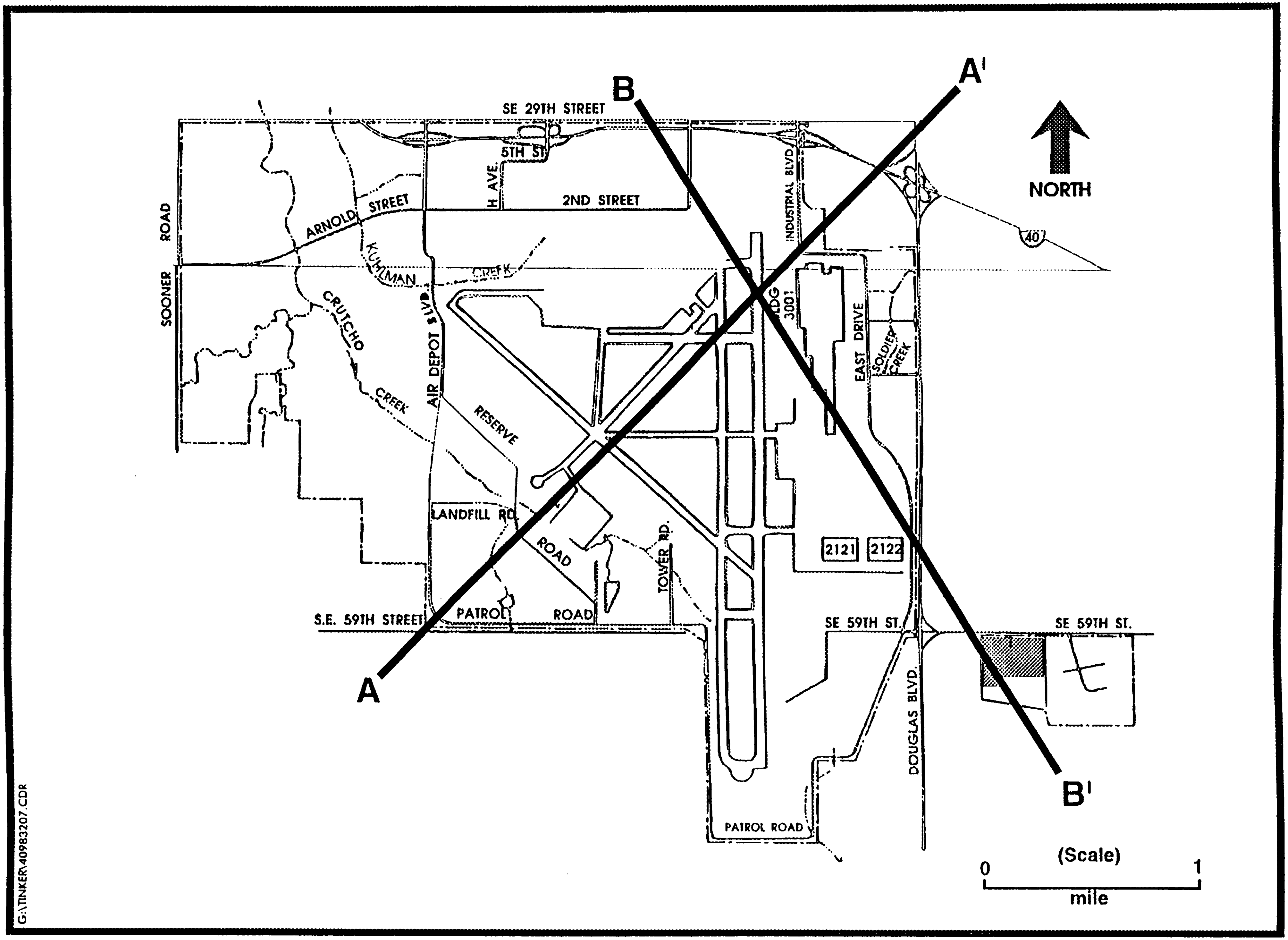

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FIGURE 3-1 TINKER AFB GEOLOGIC CROSS SECTION LOCATION MAP

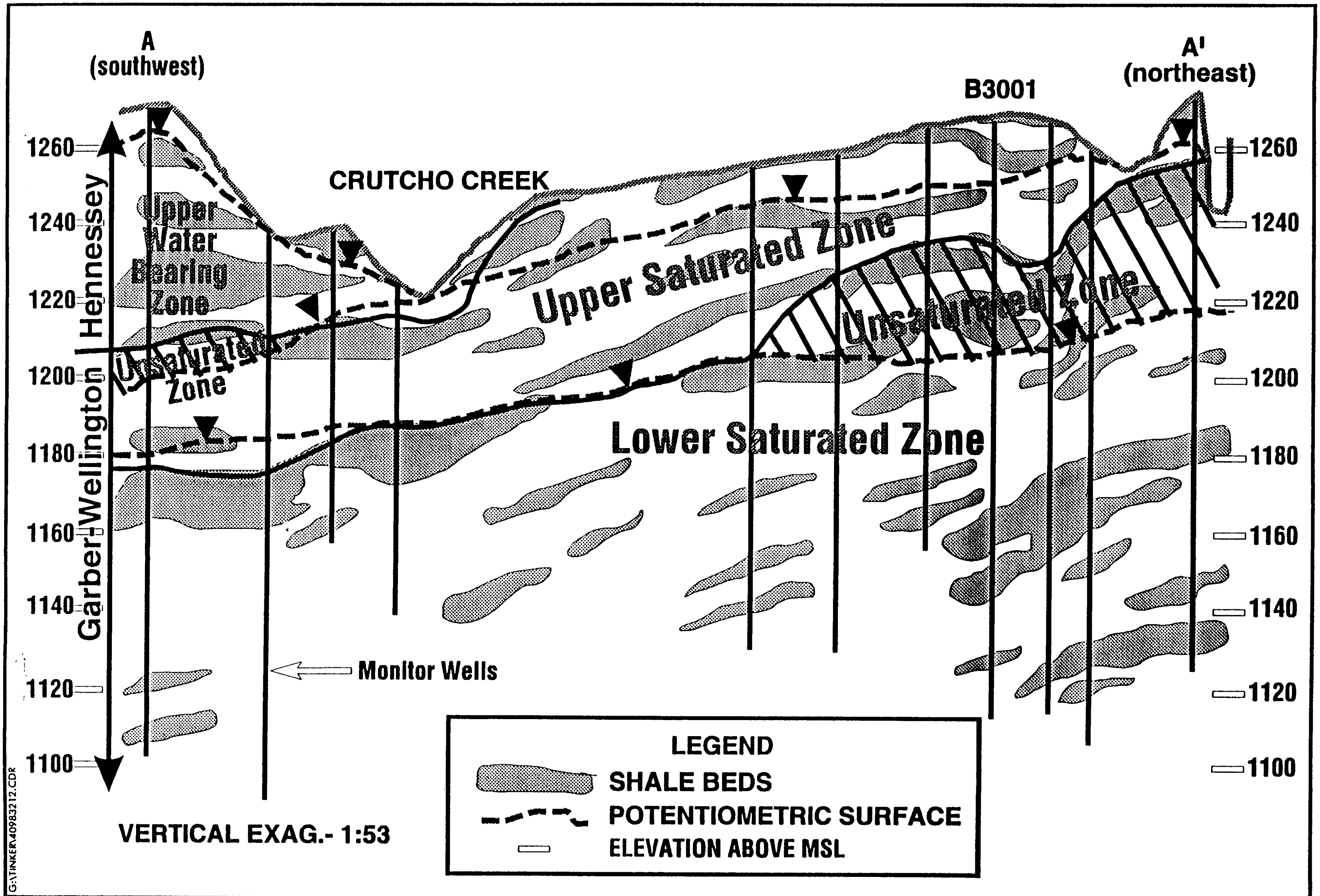

FIGURE 3-2 TINKER AFB GEOLOGIC CROSS SECTION A-A'

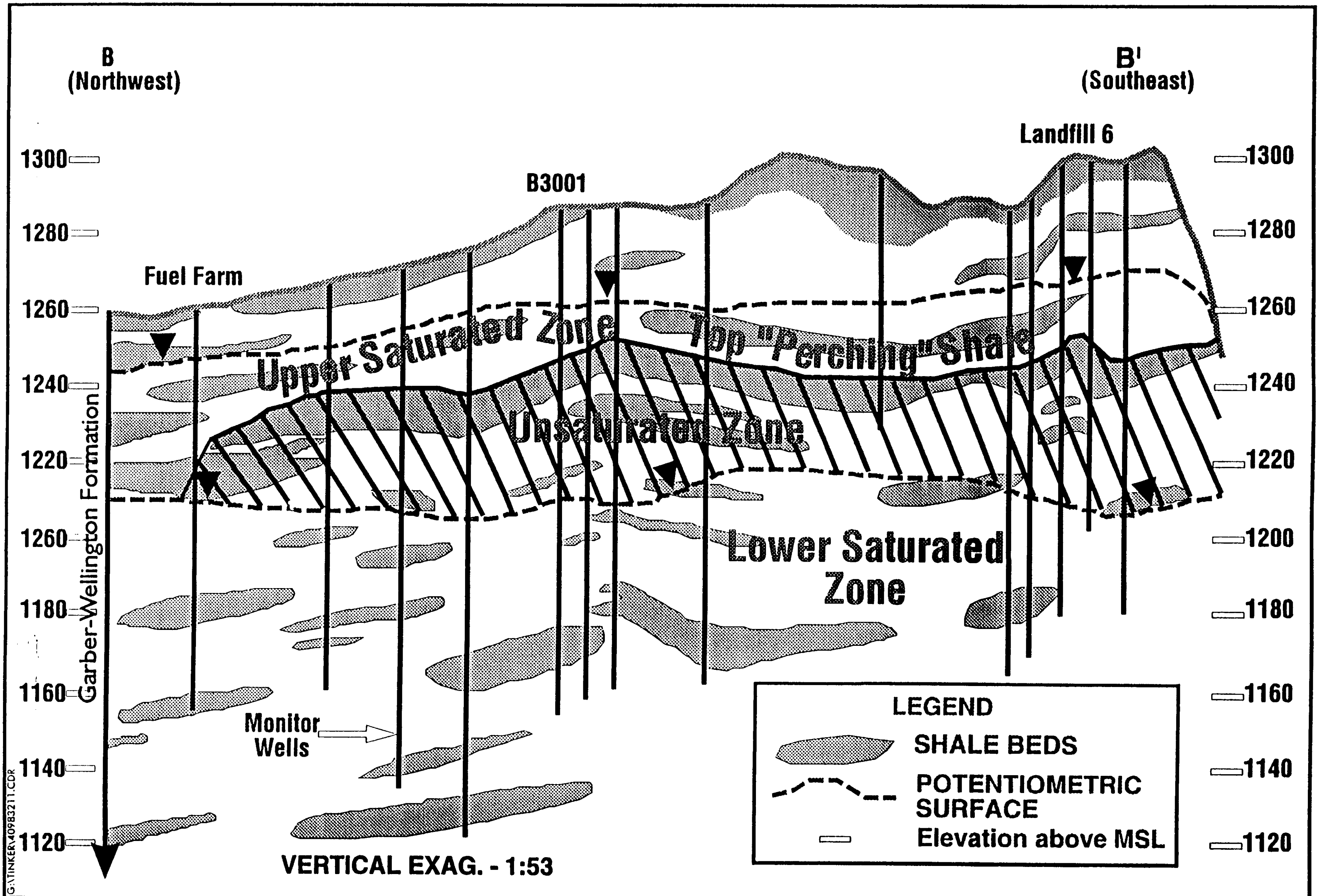

FIGURE 3-3 TINKER AFB GEOLOGIC CROSS SECTION B-B'

a generally westward direction is supported by stratigraphic correlation on geologic cross-sections at Tinker AFB. Bedrock units strike slightly west of north.

Although Tinker AFB lies in a tectonically stable area, regional dips are interrupted by buried structural features located west of the Base. A published east-to-west generalized geologic cross-section, which includes Tinker AFB, supports the existence of a northwest-trending structural trough or syncline located near the western margin of the base. The syncline is mapped adjacent to and just east of a faulted anticlinal structure located beneath the Oklahoma City Oil Field. The fault does not appear to offset Permian-age strata. There are indications that the syncline may act as a "sink" for some regional groundwater (southwest flow) at Tinker AFB before it continues to more distant discharge points.

3.2.2 Site Geology

The overburden in the area of Landfill 5 consists of clay and residual weathered shale, 8 to 12 feet thick, with some alluvial deposits in the drainages. The residual clay soil is a result of weathering of the underlying Hennessey Shale. The soil consists of soft, low plasticity clays (CL) and clayey silts (CL-ML). They are damp to moist, occasionally sandy, and vary in color from red-brown to dark gray-brown. The filled trenches are covered with 1.5 to 7.5 feet of local soil.

The bedrock consists of the lower Hennessey Shale overlying the Garber-Wellington Formation. The boundary between the two is normally chosen at the top of the first major sandstone bed. The Hennessey Shale dips to the southwest at the site and varies in thickness from 25 feet on the south edge of the landfill to less than 10 feet on the north end of the landfill. It is a red-brown, blocky clay shale with minor beds of siltstone and very fine grained sandstones. The Hennessey Shale provides a fairly impermeable layer over the Garber-Wellington Formation. The Garber-Wellington Formation below Landfill 5 is a series of red-brown, medium to fine grained sandstones, siltstones and thin shales (USACE, 1989). The sandstones vary from soft, uncemented, medium grained, clean sands to moderately hard, well cemented, clayey, fine grained sands. The shale layers are thin, soft, red-brown, and blocky. The individual shale beds may pinch out over some distance, but locally may be considered aquitards.

3.3 Hydrology

3.3.1 Regional/Tinker AFB Hydrology

The most important source of potable groundwater in the Oklahoma City metropolitan area is the Central Oklahoma aquifer system. This aquifer extends under much of central Oklahoma and includes water in the Garber Sandstone and Wellington Formation, the overlying alluvium and terrace deposits, and the underlying Chase, Council Grove, and Admire Groups. The Garber Sandstone and Wellington Formation portion of the Central Oklahoma aquifer system is commonly referred to as the "Garber-Wellington aquifer" and is considered to be a single aquifer because these units were deposited under similar conditions and because many of the best producing wells are completed in this zone. On a regional scale, the aquifer is confined above by the less permeable Hennessey Group and below by the Late Pennsylvanian Vanoss Group.

Tinker AFB lies within the limits of the Garber-Wellington Groundwater Basin. Currently, Tinker derives most of its water supply from this aquifer and supplements the supply by purchasing from the Oklahoma City Water Department. The nearby communities of Midwest City and Del City derive water supplies from both surface sources and wells tapping the aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by a municipal distribution system also depend on the Garber-Wellington aquifer. Communities presently depending upon surface supplies (such as Oklahoma City) also maintain a well system drilled into the Garber-Wellington as a standby source of water in the event of drought.

Recharge of the Garber-Wellington aquifer is accomplished principally by percolation of surface waters crossing the area of outcrop and by rainfall infiltration in this same area. Because most of Tinker AFB is located in an aquifer outcrop area, the Base is considered to be situated in a recharge zone.

According to Wood and Burton (1968) and Wickersham (1979), the quality of groundwater derived from the Garber-Wellington aquifer is generally good, although wide variations in the concentrations of some constituents are known to occur. Wells drilled to excessive depths may encounter a saline zone, generally greater than 900 feet below ground surface. Wells drilled to such depths or those accidentally encountering the saline zone are either grouted over the lowest screens or may be abandoned.

Tinker AFB presently obtains its water supplies from a distribution system comprised of 29 water wells constructed along the east and west Base boundaries and by purchase from the Oklahoma City Water Department. All Base wells are finished into the Garber-Wellington aquifer. Base wells range from 700 to 900 feet in finished depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones with a combine thickness from 103 to 184 feet (Wickersham, 1979).

Although the variability in the geology and the recharge system at Tinker AFB makes it difficult to predict local flow paths, Central Oklahoma aquifer water table data show that regional groundwater flow under Tinker varies from west-northwest to southwest, depending on location. This theory is supported by contoured potentiometric data from base monitoring wells (Figures 3-4 and 3-5) which show groundwater movement in the upper aquifer zones to generally follow regional dip. Measured normal to potentiometric contours, groundwater flow gradients range from 0.0019 to 0.0057 ft/ft. However, because flow in the near-surface portions of the aquifer at Tinker AFB is strongly influenced by topography, local stream base-levels, complex subsurface geology, location in a recharge area, and proximity to water supply wells, both direction and magnitude of groundwater movement is highly variable. The interaction of these factors not only influences regional flow but gives rise to complicated local, often transient, flow patterns at individual sites.

As a result of ongoing environmental investigations and the approximately 450 groundwater monitoring wells installed during these investigations, a better understanding of the specific hydrological framework has emerged. The current conceptual model developed by Tinker AFB (Tinker, 1993), based on the increased understanding of the hydrological framework, has been revised from an earlier model adopted by the USACE. Previous studies reported that groundwater at Tinker AFB was divided into four water-bearing zones: the perched aquifer, the top of regional aquifer, the regional aquifer, and the producing zone. In the current model, two principal water table aquifer zones and a third less extensive zone have been identified. The third is limited to the southwest quadrant. The third aquifer zone consisted of saturated siltstone and thin sandstone beds in the Hennessey Shale and equates to the UWBZ described by the USACE (1993a) at Landfills 1 through 4 (SWMUs 3 through 6). In addition, numerous shallow, thin saturated beds of siltstone and sandstone exist throughout the Base. These are of limited areal extent and are often perched.

In the current conceptual hydrologic model, an upper saturated zone (USZ) and a lower saturated zone (LSZ) are recognized in the interval from ground surface to approximately 200

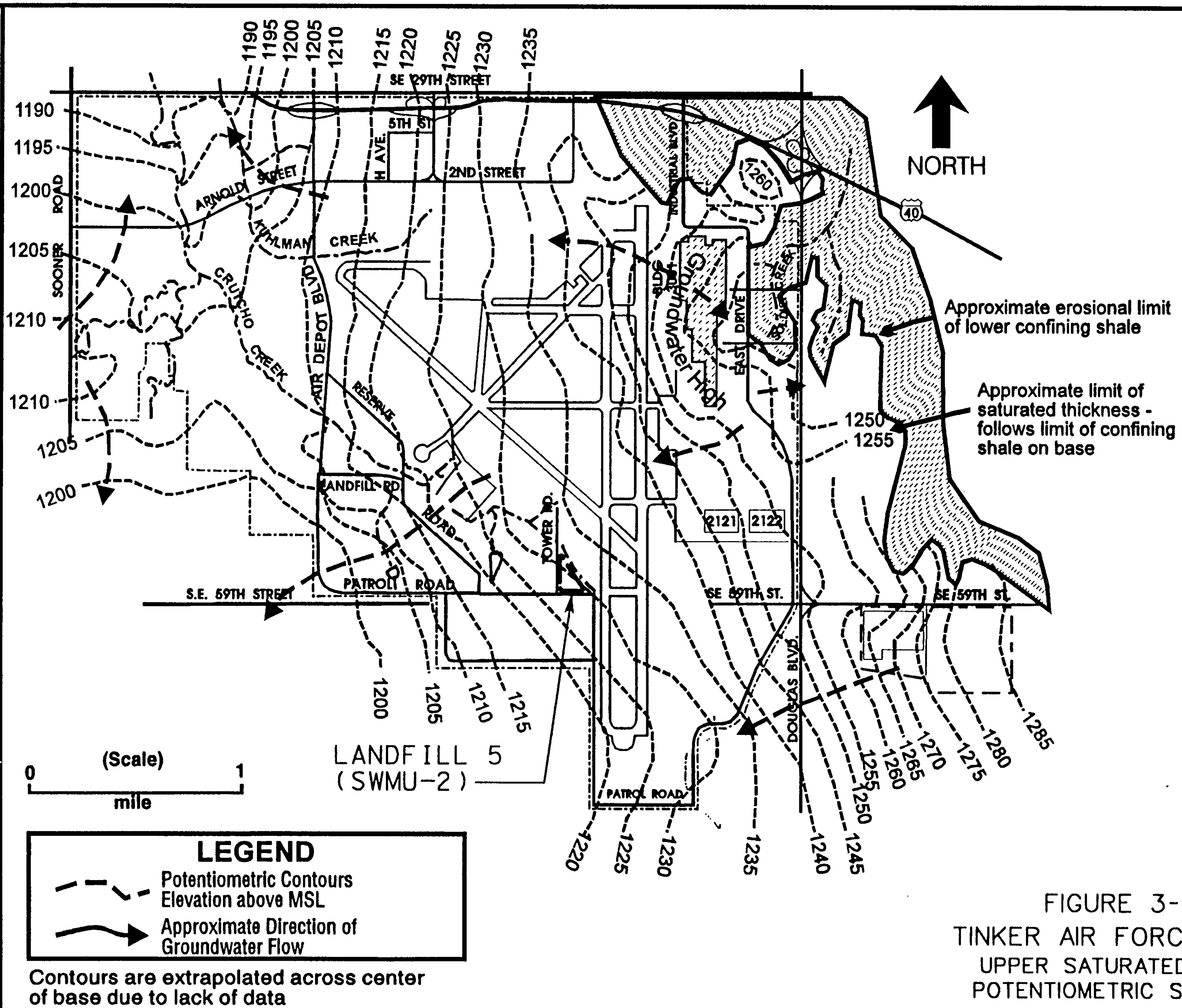

FIGURE 3-4
TINKER AIR FORCE BASE
UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE

DWG. NO.:40983209C.	INITIATOR: C. WALLACE	DRAFT. CHCK. BY:	DATE LAST REV.:	STARTING DATE: 23MAR94
PROJ. NO.:409832	PROJ. MGR.: J. TAYLOR	ENGR. CHCK. BY:	DRAWN BY:	DRAWN BY: C.E. TUMLIN

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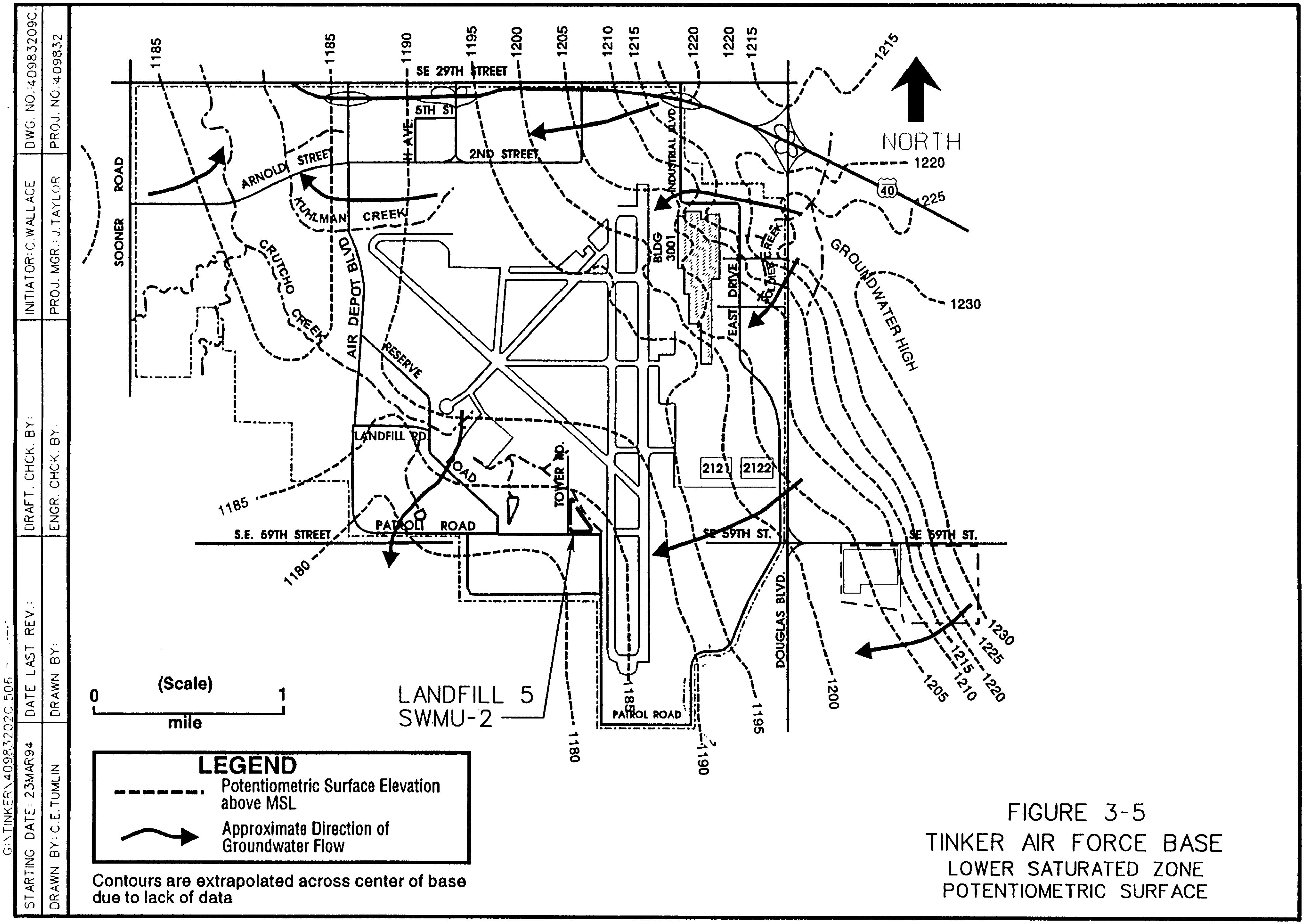


FIGURE 3-5
TINKER AIR FORCE BASE
LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE

feet. Below this is found the producing zone from which the Base draws much of its water supply. The USZ exists mainly under water table (unconfined) conditions, but may be partially confined locally. Conditions in the LSZ are difficult to determine due to screen placement and overly long sandpacks below the screen interval.

The USZ is found at a depth of 5 to 70 feet below ground surface and has a saturated thickness ranging from less than 1 foot at its eastern boundary to over 20 feet in places west of Building 3001. The USZ is erosionally truncated by Soldier Creek along the northeastern margin of Tinker AFB. This aquifer zone is considered to be a perched aquifer over the eastern one-third of Tinker AFB, where it is separated from the LSZ by an underlying confining shale layer and a vadose zone. The confining interval extends across the entire Base, but the vadose zone exists over the eastern one-third of this area. The available hydrogeologic data indicate that the vadose zone does not exist west of a north-south line located approximately 500 to 1,000 feet west of the main runway; consequently, the USZ is not perched west of this line. However, based on potentiometric head data from wells screened above and below the confining shale layer, the USZ remains a discrete aquifer zone distinct from the LSZ even over the western part of the Base. In areas where several shales interfinger to form the lower confining interval rather than a single shale bed, "gaps" may occur. In general, these "gaps" are not holes in the shale, but are places where multiple shales exist that are separated by slightly more permeable strata. Hydrologic data from monitoring wells indicate that these zones allow increased downward flow of groundwater above what normally leaks through the confining layer.

The LSZ is hydraulically interconnected and can be considered one aquifer zone down to approximately 200 feet. This area includes what was referred to by the USACE as the top of regional and regional zones. Hydrogeologic data from wells screened at different depths at the same location within this zone, however, provide evidence that locally a significant vertical (downward) component of groundwater flow exists in conjunction with lateral flow. The magnitude of the vertical component is highly variable over the Base. Preliminary evidence suggests that the LSZ is hydraulically discrete from the producing zone. Due to variations in topography, the top of the lower zone is found at depths ranging from 50 to 100 feet below ground surface under the eastern parts of the Base and as shallow as 30 feet to the west. Differences in potentiometric head values found at successive depths are due to a vertical (downward) component of groundwater flow in addition to lateral flow and the presence or absence of shale layers which locally confine the aquifer system. The LSZ extends east of the Base (east of Soldier Creek) beyond the limits of the USZ where it becomes the first groundwater zone encountered in off-Base wells. Because of the regional dip of bedding, groundwater gradient, and topography, the LSZ just east of the Base is generally encountered at depths less than 20 feet.

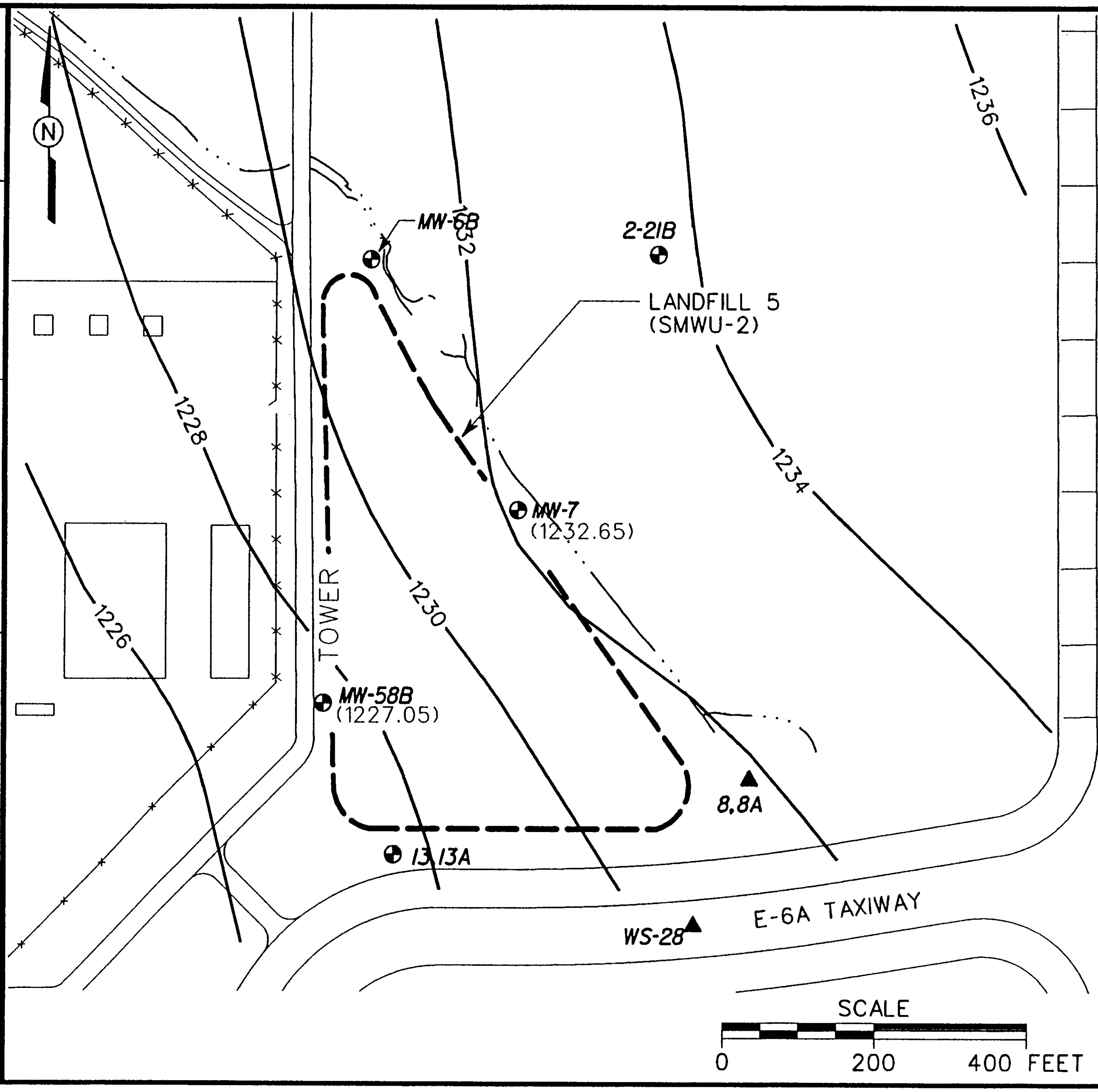
3.3.2 Site Hydrology

Earlier reports indicated that groundwater at Landfill 5 occurs in three zones which are, from the shallowest to the deepest: leachate in the landfill trench material; the USZ , which occurs below the landfill trenches; and the LSZ. The USZ groundwater was believed to flow to the southwest, with an approximate groundwater gradient of 0.027 ft/ft (USACE, 1993b, Figure 4-4). The regional potentiometric surface at Landfill 5 also was believed to flow toward the southwest with a groundwater gradient of 0.0015 ft/ft (USACE, 1993b, Figure 4-4). Previous reports also indicated that the LSZ appeared to be unconfined or partially confined, and the USZ and leachate were unconfined or partially confined. Based upon slug tests performed in the field and laboratory tests, the permeability of the LSZ varied from 2×10^{-3} centimeters per second (cm/s) to 8×10^{-4} cm/s; the permeability of the USZ varied from 1×10^{-3} cm/s to 4×10^{-4} cm/s.

Over the southeastern portion of the Base, including the Landfill 5 area, a USZ and an LSZ are recognized. Figure 3-6 shows the potentiometric surface for the USZ and Figure 3-7 shows the potentiometric surface for the LSZ at Landfill 5. In the Landfill 5 area, the USZ exists mainly under water table (unconfined) conditions, but may be partially confined locally. Conditions in the LSZ are difficult to determine due to screen placement and overly long sandpacks below the screen interval.

3.4 Soils

Three major soil types have been mapped in the Tinker AFB area and are described in Table 3-2 (U.S. Department of Agriculture [USDA], 1969). The three soil types, the Darrell-Stephenville, Renfrow-Vernon-Bethany, and Dale-Canadian-Port, consist of sandy to fine sandy loam, silt loam, and clay loam, respectively. The Darrell-Stephenville and the Renfrow-Vernon-Bethany are primarily residual soils derived from the underlying shales of the Hennessey Group. The Dale-Canadian-Port association is predominantly a stream-deposited alluvial soil restricted to stream floodplains. The thickness of the soils ranges from 12 to 60 inches. Landfill 5 lies entirely within the Renfrow-Vernon-Bethany soil association.



LEGEND:

MW7 MONITORING WELL

(1227.05) GROUNDWATER ELEVATION

▲ ABANDONED WELL

DATA DATE: MARCH 1993

C.I.: 2 FEET

NOTE:

1. DATA EXTRAPOLATED FROM ADDITIONAL DATA POINTS OUTSIDE SHOWN AREA.

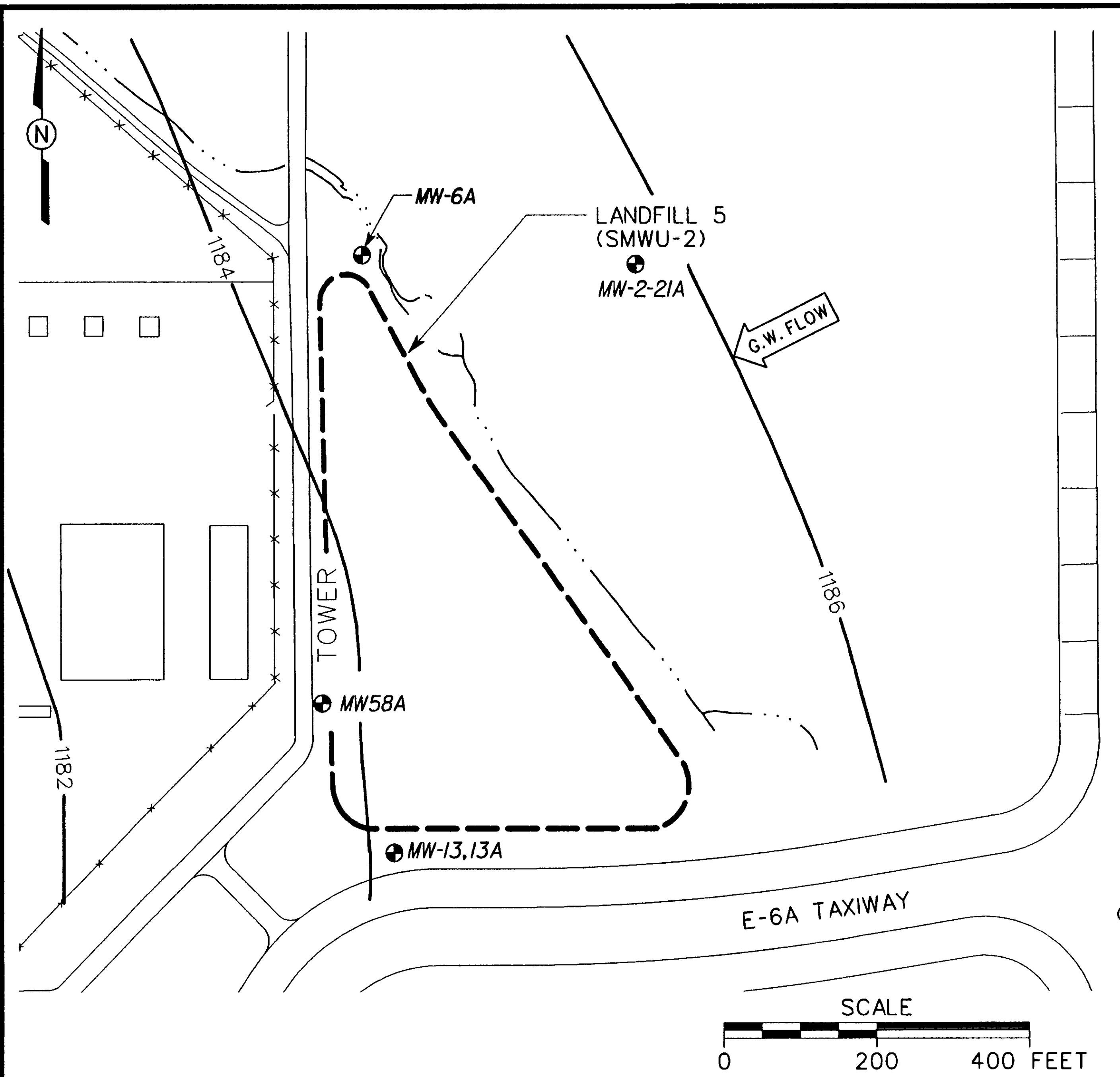
FIGURE 3-6

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 5
UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 01/14/94	DATE LAST REV.: / /	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P. TERRY	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

8/21/94 POT
FILENAME: C:\TINKER\40983202.099



LEGEND:

MW7 MONITORING WELL

DATA DATE:MARCH 1993

C.I.: 2 FEET

NOTE:

1. DATA EXTRAPOLATED FROM ADDITIONAL DATA POINTS OUTSIDE SHOWN AREA.

FIGURE 3-7

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 5
LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 01/14/94	DATE LAST REV.: / /	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P. TERRY	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

9/22/94 POT
FILENAME:G:\TINKER\40983202.107

Table 3-2

Tinker AFB Soil Associations
(Source: USDA, 1969)

Association	Description	Thickness (in.)	Unified Classification[a]	Permeability (in./hr)
Darrell-Stephenville: loamy soils of wooded uplands	Sandy loam Sandy clay loam Soft sandstone (Garber Sandstone)	12-54	SM,ML,SC	2.0-6.30
Renfrow-Vernon-Bethany: loamy and clayey soils on prairie uplands	Silt loam - clay Clay loam Shale (Fairmont Shale)	12-60	ML,CL,MH,CH	<0.60-0.20
Dale-Canadian-Port: loamy soil on low benches near large streams	Fine sandy loam Silty clay loam Loam Clay loam	12-60	SM,ML,CL	0.05-6.30

[a]Unified classifications defined in U.S. Bureau of Reclamation, 5005-86.

4.0 Source Characterization

Landfill 5 is approximately 6 acres in area. The unit was in operation from 1968 to 1970 and was used for the disposal of an estimated 75,000 cubic yards of waste. A record search conducted in 1982 (ES, 1982) identified the type of waste disposed of in Landfill 5 as general refuse with small quantities of industrial waste. Waste was disposed in trenches approximately 16 feet in depth and 50 feet wide, arranged in an east-west orientation. The trenches extended through a natural clay layer into the underlying sand/rock layer. Refuse was covered daily with 3 to 6 inches of topsoil and completed trenches were covered with 3 to 4 feet of topsoil.

During the course of the remedial investigations conducted by the USACE (1993b), four borings (L5-1 through L5-4) were drilled through the landfill trenches. The waste trenches were augered through their entire depth. Solid waste was encountered from 3.0 to 7.5 feet below the surface and was 16 to 17 feet in thickness. The waste was composited into one sample per boring for analysis. The solid waste samples were analyzed for metals, TOC, cyanide, pH, conductivity, volatile organic compounds (VOC), semivolatile compounds (SVOC), and pesticides and polychlorinated biphenyls (PCB). Metals, ten VOCs, and six SVOCs were detected in the samples.

Additional borings were drilled in June 1987 to delineate the southernmost trench at Landfill 5 in anticipation of construction of a taxiway for the E-6A TACAMO II Naval Project. Based on the investigation results, the taxiway was relocated so that none of the paved portions was constructed over any waste material. The borings were not sampled.

Landfill Trench Water. Two water samples were collected from trench water (leachate) in borings L5-1 and L5-3. The trench water samples were analyzed for metals, TOC, cyanide, pH, conductivity, VOCs and SVOCs.

Metals, VOCs, and SVOCs were detected in the trench water samples. The nature and extent of soil and groundwater contamination is discussed in detail in Chapter 5.0.

Due to the construction of a taxiway for the E-6A TACAMO II Naval Project immediately south of the landfill, a clay cap was constructed over Landfill 5 in August 1990. The site was regraded as a part of the overall plan to allow drainage of the surface water, and an 18-inch compacted clay cap covered with 12 inches of topsoil was installed to prevent infiltration of surface water. Clay materials used for the cover construction had a minimum liquid limit of 30 percent and are classified as CL or CH under the Unified Soil Classification System. The clay materials were placed in the cover system constructed at a moisture content of optimum or greater, and were compacted to a minimum of 95 percent of maximum density (standard proctor) to achieve a maximum permeability of 1 x 10^{-7} cm/s. This cover system was determined to be the most appropriate based on constructability, depth of freeze-thaw, prevention of surface water infiltration, and costs. Surface infiltration was evaluated using the "Hydrologic Evaluation of Landfill Performance" (HELP) model. In order to be as conservative as possible, the 1.5 to 7.5 feet of clay that existed over the waste materials before the compacted clay cap was placed was not considered during the model due to the variance in thickness and the unsureness of the construction techniques used during placement of the existing clay. The HELP model was developed to facilitate rapid, economical estimations of water movement across, into, through, and out of landfills. The topsoil thickness was chosen based on ease of construction and an assumed freeze-thaw depth of 8 to 10 inches. The clay thicknesses were varied to compare benefit-to-cost ratios. The cost for a 36-inch, compacted clay cap was double the cost for the 18-inch, compacted clay cover and only provided a 5 percent decrease in percolation amounts. Because of the limited increase in benefits from the thicker layers, the 18-inch clay was selected.

5.0 Contaminant Characterization

Soil and groundwater investigations were conducted at Landfill 5 to determine if any environmental contamination occurred as a result of past waste disposal practices at the landfill. Analytical results of both soil and groundwater indicated concentrations of metals above background levels. VOCs and SVOCs were also detected above background levels.

Soils. Background soil concentrations for trace metals were determined based on a study performed by the USGS (1991). The study area was confined to approximately four counties in central Oklahoma. Tinker AFB lies at the approximate center of this area. A total of 293 B-horizon soil samples were collected throughout this area. Soil samples were collected at the top of the B-horizon, which was usually 20 to 30 centimeters below the surface but ranged from 3 to 50 centimeters below the surface. For site-specific analytes for which the USGS offered no background value, the analyte was compared to an applicable action level. The background concentrations are presented in Table 5-1.

The use of B-horizon soil as selected by the USGS for metals background concentrations in soil is conservative in that the soil sampled does not reflect all possible anthropogenic influences. Most of the samples were obtained from hill crests and well drained areas in pasture and forested land, well away from roadways to minimize contamination from vehicular emissions (i.e., nearly "pristine" areas). Trace metal inputs to the study site soils on Base, however, will come from anthropogenic sources outside of the study area, in addition to those sources related to disposal activities or operations within the confines of the study site. Responsibility may thus be taken for more trace metal impacts than are actually attributable to a given site.

An additional level of conservatism was added in the manner in which the site-specific metals concentrations were compared to the background levels. Typically, the environmental concentrations of trace metals at study sites are represented by the arithmetic upper 95th confidence interval on the mean of a normal distribution. This upper 95th confidence interval value is then compared to the background values. The intent of this typical approach is to estimate a Reasonable Maximum Exposure (RME) case (i.e., well above the average case) that is still within the range of possible exposures.

Table 5-1

Background Concentrations of Trace Metals in Surface Soils[a]
SWMU-2, Landfill 5, Tinker AFB

(Page 1 of 2)

Analyte	Lower Detection Limit	Background Concentration Range: Minimum Value	Background Concentration Range: Maximum Value
Concentration in %			
Aluminum	0.005	0.38	8.9
Cadmium	0.005	0.01	9.4
Iron	0.005	0.18	5.8
Magnesium	0.005	0.02	5.3
Phosphorous	0.005	0.06	0.019
Potassium	0.05	0.1	2.4
Sodium	0.005	0.02	0.99
Titanium	0.005	0.04	0.42
Concentrations in ppm			
Arsenic	0.1	0.6	21
Barium	1	47	6400
Beryllium	1	<1	3
Bismuth	10	<DL[b]	<DL
Cadmium	2	<DL	<DL
Cerium	4	14	110
Chromium	1	5	110
Cobalt	1	<1	27
Copper	1	<1	59
Europium	2	---[c]	---
Gallium	4	<4	23
Gold	8	<DL	<DL
Holmium	4	<DL	<DL
Lanthanum	2	7	51
Lead	4	<4	27
Lithium	2	5	100

Table 5-1

(Page 2 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Manganese	10	24	3400
Molybdenum	2	<DL	<DL
Neodymium	4	6	47
Nickel	2	<2	61
Niobium	4	<4	16
Scandium	2	<2	15
Selenium	0.1	<0.1	1.2
Silver	2	<DL	<DL
Strontium	2	13	300
Tantalum	40	<DL	<DL
Thorium	1	<1.40	15.00
Tin	10	<DL	<DL
Uranium	0.1	0.650	6.400
Vanadium	2	5	220
Ytterbium	1	<1	3
Yttrium	2	3	43
Zinc	2	3	79

[a]All B-horizon soil samples (293) from USGS, 1991.
[b]All concentrations below the lower limits of determination.
[c]Insufficient or no data.

To expedite this comparison and establish greater conservatism, the maximum concentration found at the site of concern, rather than the upper 95th confidence interval value, was compared to the USGS background values. If the environmental concentration of a particular analyte was below or within the minimum-maximum range of the USGS background concentrations, that analyte was considered to be naturally occurring and of no further concern to this investigation. Given the conservative approach of the comparisons, site-specific metals concentrations would have to significantly exceed the USGS background levels and be attributable to operations at the site before they would be considered a contaminant of concern.

The numerical comparison of site-specific metals concentrations to the USGS background concentrations is presented in Section 5.2.

Four borings were drilled into the Landfill 5 trenches. Solid waste samples were collected from the borings. A soil sample from the seep located on the north east edge of the landfill was also collected and analyzed as part of the investigation. The solid waste and soil samples were analyzed for metals, TOC, cyanide, pH, VOCs, and SVOCs. Concentrations of metals above background levels and some VOCs and SVOCs were detected in the samples. A summary of the chemical data is presented in Table 5-2. Frequency of chemical constituents is presented in Table 5-3.

Groundwater. The quality of groundwater beneath the site was investigated through the installation of a total of nine monitoring wells at the landfill. Five of the wells, MW-6, MW-7, MW-8, MW-13, and MW-58B were installed into the USZ and four wells MW-6A, MW-8A, MW-13A, and MW-58A were installed into the LSZ. Table 5-4 presents a summary of the monitoring well data including top of casing elevation, total well depth and zone monitored by each well. Four monitoring wells were sampled in 1986 and 1987. In September 1988 and 1989 all nine monitoring wells were sampled at the landfill. However, during the construction of the E-6A taxiway two of the monitoring wells (MW-8 and MW-8A) were abandoned. Consequently, during the subsequent sampling effort, November 1992 only the remaining seven wells were sampled. Additionally, a two-well cluster consisting of an USZ and an LSZ well (2-21A and 2-21B) was installed to the northeast of the site in September 1993. The well cluster was installed upgradient of the landfill to monitor potential migration of contaminants from upgradient areas.

Table 5-2

Summary of Solid Waste Analytical Results
SWMU-2, Landfill 5, Tinker AFB

(Page 1 of 2)

Analyte	L5-1	L5-2	L5-3	L5-4	Seep	Background
Volatile Organics (µg/kg)						
2-Butanone	1100	375	580	410	16,000	
2-Chloroethylvinylether	<251	<256	<248	<132	220	
2-Hexanone	85 J	<256	<248	90 J	210	
4-Methyl-2-pentanone	230 J	<256	136 J	120 J	7700	
Acetone	4500	3400	4300	2100	24,000	
Chlorobenzene	120 J	<128	<124	<66		
Ethyl benzene	180	<128	<124	37 J	ND	
Methylene chloride	<125	<128	124 J	91	38	
Toluene	250	<128	130	100	42	
Vinyl acetate	<251	<256	98 J	<132		
Xylene (Total)	890	117 J	310	190	ND	
Semivolatile Organics (µg/kg)						
2-Methylphenol	<25,000	<26,000	13,000 J	330 J		
4-Methylphenol	<25,000	15,000 J	16,000 J	3600	2600	
Bis(2-ethylhexyl)phthalate	6200 J	5400 J	<25,000	940 J		
Di-n-butyl phthalate	<25,000	2800 J	<25,000	360 J		
Diethyl phthalate	<25,000	4000 J	12,000 J	<2200		

KN/1256/SWMU2/SWMU2.5-2/04-07-94/D4 1:49pm

Table 5-2

(Page 2 of 2)

Analyte	L5-1	L5-2	L5-3	L5-4	Seep	Background
Phenol	<25,000	<26000	62,000	1700 J	1500	
General Chemistry						
pH	6.89	6.29	6.32	6.23		
Conductivity (µmhos/cm)	1300	3000	1300	1400		
TOC (mg/kg)	78,000	80,000	33,000	25,000		
Metals (µg/kg)						
Cyanide	800	1900	1600	6900		
Silver	2000	4700	8000	4800	700	560
Arsenic	5000	2400	1700	1900	2600	1100
Barium	230,000	450,000	200,000	460,000	420,000	220,000
Cadmium	15,000	25,000	270,000	28,000	3000	720
Chromium	350,000	150,000	280,000	30,000	39,000	23,000
Lead	47,000	86,000	480,000	140,000	34,000	15,000
Mercury	680	410	1200	260		<100
Nickel	2,700,000	4,100,000	6,300,000	340,000	53,000	21,000
Selenium	<100	<100	910	<100	200	100
Zinc	110,000	1,100,000	770,000	550,000	620,000	25,000

ND = Not detected.
J = Estimated value.

KN/1256/SWMU2/SWMU2.5-2/04-07-94/D4 1:49pm

Table 5-3

Frequency of Detected Analytes in Solid Waste SWMU-2, Landfill 5, Tinker AFB

(Page 1 of 2)

Analyte	Frequency of Detection	Range of Detected Concentration	Average Concentration	Location of Maximum Concentration
Volatile Organics (μg/kg)				
2-Butanone	4/4	375-1100	616	L5-1
2-Hexanone	2/4	85-90	87	L5-4
4-Methyl-2-pentanone	3/4	120-230	162	L5-1
Acetone	4/4	2100-4500	3575	L5-1
Chlorobenzene	1/4	<66-120	120	L5-1
Ethyl benzene	2/4	37-180	108	L5-1
Methylene chloride	2/4	91-124	85	L5-3
Toluene	3/4	100-250	160	L5-1
Vinyl acetate	1/4	98-<256	98	L5-3
Xylene (Total)	4/4	117-890	377	L5-1
Semivolatile Organics (μg/kg)				
4-Methylphenol	3/4	3600-16,000	11,533	L5-3
Bis(2 ethylhexyl) phthalate	3/4	940-6200	4180	L5-1
Diethyl phthalate	2/4	4000-12,000	8000	L5-3
Di-n-butyl phthalate	2/4	360-2800	1580	L5-2
Phenol	2/4	1700-62,000	31,850	L5-3
2-Methylphenol	2/4	330-13,000	6665	L5-3
General Chemistry				
Cyanide (μg/kg)	4/4	800-6900	2800	L5-4
pH	3/4	6.23-6.89	6-43	L5-1
Conductivity (μmhos/cm)	4/4	1300-3000	1750	L5-2
TOC (mg/kg)	4/4	25,000-80,000	54,000	L5-2
Metals (μg/kg)				
Arsenic	4/4	1700-5000	2750	L5-1
Barium	4/4	20,000-460,000	335,000	L5-4

Table 5-3

(Page 2 of 2)

Analyte	Frequency of Detection	Range of Detected Concentration	Average Concentration	Location of Maximum Concentration
Metals (μg/kg) (Continued)				
Cadmium	4/4	15,000-270,000	84,500	L5-3
Chromium	4/4	30,000-350,000	202,500	L5-1
Lead	4/4	47,000-480,000	188,250	L5-3
Mercury	4/4	260-1200	638	L5-3
Nickel	4/4	340,000-6,300,000	3,360,000	L5-3
Selenium	1/4	<100-910	910	L5-3
Silver	4/4	2000-8000	4875	L5-3
Zinc	4/4	110,000-1,100,000	632,500	L5-2

Table 5-4

Groundwater Monitoring Well Data
SWMU-2, Landfill 5, Tinker AFB

Monitoring Well	Date Drilled	Total Depth (ft)	Screened Interval (ft)	Top of Casing Elevation (ft)	Zone Monitored
MW-6	before 1982	29	22.2-27.2	1243.5	USZ[a]
MW-6A	12-04-86	90	57-67	1243.1	LSZ[b]
MW-7	before 1982	22	14.1-19.1	1246.7	USZ
MW-8	before 1982	20.5	13.3-18.3	1250.5	USZ
MW-8A	10-17-86	92.5	77-87	1251.1	LSZ
MW-13	11-20-83	55	45-55	1258.7	USZ
MW-13A	10-26-86	92.5	77-87	1258.8	LSZ
MW-58A	09-17-86	99.8	87-97	1257.1	LSZ
MW-58B	09-17-86	99.8	27-37	1257.0	USZ

[a]USZ - Upper Saturated Zone
[b]LSZ - Lower Saturated Zone

Trench water was sampled from open boreholes through the upper part of the waste material. Sampling of the existing and newly installed monitoring wells was performed again in September 1988 and 1989. Water samples were analyzed for metals, TOC, chloride, sulfate, cyanide, pH, conductivity, volatile organics and semivolatile organics. Table 5-5 presents a summary of analytical results from trench water. Tables 5-6 and 5-7 summarize the analytical results for the USZ and the LSZ, respectively.

5.1 Constituents of Potential Concern

Analytical results from soil and groundwater samples from the Landfill 5 site are available from past IRP investigation activities. Evaluation of these analytical results for the purpose of identifying constituents of potential concern with respect to both human health and the ecological impacts has not been performed. However, an interpretation has been made comparing the analytical results to elemental background concentrations in soils and, in the case of synthetic organic compounds in groundwater, to maximum contaminant levels. The following section summarizes these interpretations.

5.2 Soil Characterization

The soil sample from the seep location contained concentrations of cadmium, lead, and zinc above background values. Seven VOCs and two SVOCs were found in the seep sample. The volatile organics included methylene chloride, acetone, 2-butanone, 2-chloroethylvinylether, 2-hexanone, 4-methyl-2-pentanone, and toluene. The two SVOCs were phenol and 4-methylphenol.

Concentrations of cadmium, chromium, lead, nickel, mercury, silver, and zinc were found above the background concentrations for heavy metals in the solid waste samples. Two VOCs and six SVOCs were detected in the four waste samples. The VOCs included acetone, toluene, xylene, 2-butanone, 4-methyl-2-pentanone, 2-hexanone, ethyl benzene, chlorobenzene, vinyl acetate, and methylene chloride. The six SVOCs were phenol, 4-methylphenol, bis(2-ethylhexyl)phthalate, diethyl phthalate, 2-methylphenol, and di-n-butyl phthalate.

The maximum concentration of seven of the ten volatile organics were found in boring L5-1, located in the southern portion of the landfill. The highest volatile organic concentration detected was acetone at 4,500 micrograms per kilogram (μg/kg) in boring L5-1. The maximum concentration of the semivolatile organics were found in boring L5-3 in the center of the landfill. Phenol was the highest semivolatile organic concentration found at 62,000 μg/kg in boring L5-3. Seven heavy metals (cadmium, chromium, lead, mercury, nickel,

Table 5-5

Summary of Trench Water Analytical Results
SWMU-2, Landfill 5, Tinker AFB

Analyte	Sample Location	
	L5-1	L5-3
Volatile Organics (μg/L)		
2-Butanone	610	140
4-Methyl-2-pentanone	630	<100
Acetone	1900	440
Ethyl benzene	340	<18
Toluene	230	200
Xylene (Total)	860	<45
Semivolatile Organics (μg/L)		
2-Methylphenol	<50	180
4-Methylphenol	<50	120
Benzoic acid	260	<250
Phenol	<33	410
General Chemistry		
pH	6.67	6.26
Conductivity (μmhos/cm)	2.48	614
TOC (mg/L)	570	250
Metals (μg/L)		
Arsenic	3.9	2.4
Barium	960	<500
Cadmium	20	20
Chromium	48	<10
Lead	120	50
Nickel	290	250
Silver	13	<10
Zinc	1300	1600

Table 5-6

Summary of Upper Saturated Zone Analytical Data
SWMU-2, Landfill 5, Tinker AFB

(Page 1 of 3)

Well No.	MW-6	MW-6	MW-6	MW-6	MW-7	MW-7	MW-7	MW-7	MW-8	MW-13	MW-13	MW-13	MW-58B	MW-58B	MW-58B	MW-58B
Sample Date	1986	1988	1989	1992	1986	1988	1989	1992	1986	1986	1988	1989	1987	1988	1989	1992
Analyte																
Volatile Organics (µg/L)																
1,1-Dichloroethane	<5	<5	<5	1	<5	<5	<5	1	<5	<5	<5	<5	<5	2 J	<5	6
1,2-Dichloroethene (total)	NA	5	87 B	<5	NA	4 J	<5	<5	NA	NA	<5	<5	NA	91	99	<5
1,4-Dichlorobenzene	<10	<10	<10	<10	<10	<10	0.8 J	<10	<10	<10	<10	<10	<10	5 J	8 J	<10
2-Butanone	<10	<10	<10	<10	<10	<10	<10	<10	NA	<10	<10	<10	<10	140	<10	<10
Acetone	870	<10	<10	<10	56	<10	<10	<10	<10	180	<10	<10	<10	88	27	<10
Benzene	<0.5	<0.5	<0.5	1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	14
Chlorobenzene	<5	<5	<5	<5	<5	<5	<5	0.7	<5	<5	<5	<5	NA	<5	2 J	2
Chloroethane	<10	12	<10	<10	<10	<10	<10	ND	<10	<10	<10	<10	<10	<10	4 J	4
Chloroform	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	6.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.8
Dibromochloromethane	38	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ethyl benzene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	16	7	9
Isopropylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	5
Methylene chloride	<5	<5	<5	1 B	<5	<5	2 BJ	1 B	<5	<5	<5	<5	<5	94	4 J	2 B
Naphthalene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	2 B	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	5 B
Tert-butylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.8
Toluene	<5	0.7 J	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	6	6	2

Table 5-6

(Page 2 of 3)

Well No.	MW-6	MW-6	MW-6	MW-6	MW-7	MW-7	MW-7	MW-7	MW-8	MW-13	MW-13	MW-13	MW-58B	MW-58B	MW-58B	MW-58B
Sample Date	1986	1988	1989	1992	1986	1988	1989	1992	1986	1986	1988	1989	1987	1988	1989	1992
Analyte																
Trans-1,2-dichloroethene	720	NA	NA	4	43	NA	NA	<10	<10	<10	NA	NA	210	NA	NA	4
Trichloroethene	<5	<5	<5	1	12	<5	<5	<5	<5	14	3 J	1 J	31	45	<5	6
1,2,4-Trimethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	2.0
Vinyl chloride	200	22	20	280	<10	<10	<10	<10	<10	<10	<10	<10	6 J	<10	3 J	2
Xylene (total)	<5	<5	<5	0.6	<5	<5	<5	<5	<5	<5	<5	<5	<5	5	23	1.6
1,2-Dichlorobenzene	<10	<10	<10	<10	<10	<10	0.3 J	<10	NA	<10	<10	<10	<10	<10	<10	0.9
Cis 1,2-Dichloroethene	<0.5	<0.5	<0.5	1100	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	22
1,3-Dichlorobenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	16
1,4-Dichlorobenzene	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	9 J
1,2-Dichloroethane	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	4
1,3,5-Trimethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.4 J
Semivolatile Organics (µg/L)																
4-Methylphenol	<10	<10	<10	<10	<10	<10	<10	<10	NA	<10	<10	<10	<10	9 J	11	<10
Benzoic Acid	<50	<48	<50	<50	<50	<49	<50	<50	NA	<50	<49	<50	<50	24 J	9 J	<50
Bis(2-ethylhexyl)phthalate	29	13	10	<10	<10	39	<10	15	NA	<10	<10	<10	9 J	21	5 J	<10
Di-n-octyl phthalate	10 J	<10	3 J	<10	<10	<10	1 J	<10	NA	<10	<10	<10	7 J	<10	4 J	<10
Diethyl phthalate	<10	<10	<10	<10	<10	<10	.4 J	<10	NA	<10	<10	<10	14	8 J	13	37
Dimethyl phthalate	<10	<10	3 J	<10	<10	<10	<10	<10	NA	<10	<10	<10	<10	<10	<10	<10

Table 5-6

(Page 3 of 3)

Well No.	MW-6	MW-6	MW-6	MW-6	MW-7	MW-7	MW-7	MW-7	MW-8	MW-13	MW-13	MW-13	MW-58B	MW-58B	MW-58B	MW-58B
Sample Date	1986	1988	1989	1992	1986	1988	1989	1992	1986	1986	1988	1989	1987	1988	1989	1992
Analyte																
Naphthalene	<10	<10	<10	<10	<10	<10	<10	<10	NA	<10	<10	<10	<10	<10	1 J	<10
Phenol	<10	<10	<10	<10	<10	<10	<10	<10	NA	<10	<10	<10	3 J	4 J	<10	<10
General Chemistry																
pH	7.13	7.28	6.92	NA	7.3	7.08	6.79	NA	7.47	7.08	7.20	NA	6.92	6.85	6.93	NA
Sulfate (mg/L)	15.5	19	19	NA	3	7.3	19	NA	NA	5	13	8.5	58	29	32	NA
Chloride (mg/L)	30	9	9	NA	15	33	58	NA	NA	100	120	160	120	210	9.0	NA
TOC (mg/L)	7.7	NA	2.58	6500	3.7	NA	0.849	4300	7.16	7	NA	1.93	16	NA	9.87	30,000
Conductivity (μmhos/cm)	1097	881	760	NA	759	820	800	NA	1349	1351	1297	NA	1888	1995	1590	NA
Metals (μg/L)																
Arsenic	<1	2	1.1	3.8	2.9	3.8	3.7	5.1	4.9	<1	1.5	<1	17	27	24	17.4
Barium	790	840	790	812	2100	2300	4900	2450	2300	<500	640	830	3500	4200	4200	2000
Cadmium	10	<5	<5	<5	10	<5	5	<5	13	<8	<5	<5	<7.5	11	12	<5
Chromium	<10	<5	<5	<5	<10	<5	<5	<5	250	<10	<5	6	20	5	9.2	<5
Lead	28	10	<10	<5	23	<10	<10	<10	210	33	<10	<10	53	21	16	<10
Mercury	1.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.52	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	240	NA	NA	<15	150	NA	NA	<15	430	53	NA	NA	55	NA	NA	48.2
Zinc	35	NA	82	<5	53	NA	15	<5	1300	53	NA	11	35	NA	55	<5

NA = Not analyzed.
J = Estimated value.
B = Compound also found in blank.

KN/1256/SWMU2/SWMU2.5-6/04-07-94/D9 2:08pm

Table 5-7

Summary of Lower Saturated Zone Analytical Data
SWMU-2, Landfill 5, Tinker AFB

(Page 1 of 3)

	MW-6A	MW-6A	MW-6A	MW-6A	MW-8A	MW-8A	MW-8A	MW-13A	MW-13A	MW-13A	MW-58A	MW-58A	MW-58A	MW-58A
	1987	1988	1989	1992	1987	1988	1989	1987	1988	1989	1987	1988	1989	1992
Compound														
Volatile Organics (µg/L)														
Acetone	34	<10	14	<10	<10	<10	<10	3 J	<10	<10	11	<10	<10	<10
Benzene	4 J	<5	<5	<5	19	<5	<5	<5	<5	<5	<5	<5	<5	2
Chlorobenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.9
Ethyl benzene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	0.6 J	<5	1.0
Isopropylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	5.0
Methylene chloride	<5	<5	3 BJ	1 B	4 J	<5	13 B	<5	<5	<5	<5	<5	<5	<5
Tetrachloroethene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	2.0
Toluene	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	6	< 5	0.3 J
Trans-1,2-dichloroethene	10	NA	NA	NA	<5	NA	NA	NA	NA	NA	14	NA	NA	NA
Trichloroethene	<5	<5	<5	<5	<5	<5	<5	6	18	<5	45	1 J	4 BJ	6.0
Xylene (Total)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	0.4 J	<5	0.5 J
Cis 1,2-dichloroethene	<0.5	<0.5	<0.5	9	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5
1,2-Dichlorobenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.4 J
1,3,5-Trimethylbenzene	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	6.0

Table 5-7

(Page 2 of 3)

	MW-6A	MW-6A	MW-6A	MW-6A	MW-8A	MW-8A	MW-8A	MW-13A	MW-13A	MW-13A	MW-58A	MW-58A	MW-58A	MW-58A
	1987	1988	1989	1992	1987	1988	1989	1987	1988	1989	1987	1988	1989	1992
Semivolatile Organics (µg/L)														
Benzoic acid	<50	<48	<50	<50	<50	<49	9 J	<50	<49	<50	<50	<49	<50	<50
Bis(2-ethylhexyl)phthalate	<10	13	<10	<10	<10	<10	4 J	3 J	18	5 J	17	21	6 J	<10
Di-n-octyl phthalate	<10	<10	3 J	<10	<10	<10	8 J	2 J	<10	4 J	7 J	<10	3 J	<10
Dimethyl phthalate	<10	<10	<10	<10	<10	<10	7 J	<10	<10	13	<10	<10	18	9.0
Naphthalene	<0.5	<0.5	<0.5	2B	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.8 B
Phenol	5 J	<10	<10	<10	<10	<10	<10	4 J	<10	9 J	<10	<10	<10	<10
General Chemistry														
pH	11.43	7.38	7.01	NA	10.25	11.05	10.96	8.99	10.58	10.3	11.43	9.87	9.61	NA
Sulfate (mg/L)	29	9.7	22	NA	15	8.2	<2	19	4.4	4.5	37	25	47	NA
Chloride (mg/L)	11	20	17	NA	27	32	29	29	31	7.7	100	76	<2	NA
Conductivity (µmhos/cm)	631	552	400	NA	388	374	1010	670	382	330	1195	452	510	NA
TOC (mg/L)	5.7	NA	7.98	2.4	1.9	NA	1.43	3.0	NA	1.64	3.8	NA	9.59	1.7
Metals (µg/L)														
Arsenic	6	3.6	2.7	<1	9.6	<1	<1	5.7	1.6	<1	3.5	26	7.0	<1
Barium	4900	1400	1900	379	<500	130	410	5600	320	620	<500	420	310	467
Chromium	10	<5	5.8	<10	<10	<5	5.2	180	5	5.2	15	5	9.2	<10
Iron	63	NA	NA	NA	1200	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	30	29	22	<10	40	<10	<10	80	10	<10	43	12	<10	<10

Table 5-7

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	MW-6A	MW-6A	MW-6A	MW-6A	MW-8A	MW-8A	MW-8A	MW-13A	MW-13A	MW-13A	MW-58A	MW-58A	MW-58A	MW-58A
	1987	1988	1989	1992	1987	1988	1989	1987	1988	1989	1987	1988	1989	1992
Manganese	1000	NA	NA	NA	17	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	65	NA	NA	<15	10	NA	NA	120	NA	NA	18	NA	NA	<15
Zinc	98	NA	19	<5	20	NA	<5	160	NA	46	23	NA	25	<5
Mercury	<0.1	<0.1	<0.1	<0.1	0.11	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Selenium	<0.4	<0.4	<0.4	<0.4	1.1	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4

B = Analyte was found in the associated blank as well as the sample.
J = Estimated value.

silver, and zinc) were found above background levels in all four trench samples. The maximum metal concentration found was nickel at 6,300,000 μg/kg in boring L5-3. Cyanide was also detected in all borings, with the highest concentration of 6,900 μg/kg found in boring L5-4. Table 5-3 presents the frequency of chemical constituents in solid waste.

5.3 Groundwater Characterization

Landfill Trench Water. Landfill trench water included water found in the landfill trenches and was obtained by sampling water in borings L5-1 and L5-3 at the time of drilling.

Three heavy metals, cadmium, lead, and nickel, were detected above their respective current maximum contaminant levels (MCL). Cadmium was detected in both samples at a concentration of 20 micrograms per liter (μg/L). Lead was detected in concentrations of 120 μ/L and 50 μ/L in borings L5-1 and L5-3, respectively. Nickel was found above the MCL of 100 μg/L in boring L5-1 and L5-3 at concentrations of 290 and 250 μg/L, respectively. Other metals were detected at concentrations below the MCLs.

Six volatile organics were detected in both L5-1 and L5-3: acetone, 2-butanone, 4-methyl-2-pentanone, toluene, ethyl benzene, and xylene. Current MCLs exist for three of the six volatile compounds (toluene, ethyl benzene, and xylene); however, these three contaminants were detected below the MCLs.

Four SVOCs were detected in both L5-1 and L5-3. Phenol was found at a concentration of 410 μg/L in L5-3. Benzoic acid was found in L5-1 at a concentration of 260 μg/L. The compounds 2-methylphenol and 4-methylphenol were found in L5-3 at concentrations of 180 and 120 μg/L, respectively. There are no current or proposed MCLs for the semivolatile compounds detected in the trench water samples. Table 5-5 contains a summary of the contaminants in trench water.

Upper Saturated Zone. The chemical quality of the USZ groundwater was determined by the sampling of five wells. Wells MW-6, MW-7 and MW-8 were located hydraulically upgradient and wells MW-13 and MW-58B were located downgradient of the site. The groundwater flow is to the southwest away from Crutcho Creek. The concentrations of the contaminants detected in the USZ during the four sampling events (1987, 1988, 1989, 1992) are shown in Table 5-6 for each well. Table 5-8 contains the frequency, range, and location of maximum concentrations for these contaminants.

Sixteen volatile organic compounds were found in the USZ. These compounds are vinyl chloride, chloroethane, methylene chloride, acetone, 1,1-dichloroethane, trans-1,2-dichloroethene, 1,2-dichloroethene (total), 2-butanone, trichloroethene, toluene, chlorobenzene, ethyl benzene, xylene (total), 1,4-dichlorobenzene, dibromochloromethane, and 1,2 dichlorobenzene. Acetone was detected in five samples: in MW-6, MW-7, MW-13 in 1986 sampling; and in MW-58B in 1988 and 1989. The compound trans-1,2-dichloroethene was found in MW-6 and MW-7 in 1986 sampling and in MW-58B in 1987; trans-1,2-dichloroethene was detected above the MCL in MW-6 and MW-58B samples. However, the compound was not analyzed for in the subsequent sampling events. The analyte 1,2-dichloroethene (total) was substituted for trans-1,2-dichloroethene in the subsequent sampling events. The compound 1,2-dichloroethene (total) results include trans-1,2-dichloroethene concentration. In 1988 and 1989, 1,2-dichloroethene (total) was analyzed for and found in MW-6 and MW-58B; in MW-7 it was found in the 1988 sample only. Trichloroethene was detected in several samples. Trichloroethene was detected at concentrations above the MCL in wells MW-7, MW-13 and MW-58B. Methylene chloride was detected in MW-58B in 1988 at concentration above MCL.

Of the SVOCs, bis(2-ethylhexyl)phthalate was found in 7 of the 12 samples at concentrations ranging from 9 to 39 µg/L. These concentrations were above the MCL for bis(2-ethylhexyl)-phthalate (6 µg/L). However, this compound is a common plasticizer found in many plastic items utilized in the laboratory; thus, it is a common laboratory contaminant. All other semivolatile compounds that were detected in the USZ data samples do not have any current or proposed MCLs. These detected concentrations were near or below quantitation limits.

Barium was detected above the MCL (2,000 µg/L) in MW-7, MW-8, and MW-58B. Cadmium was detected above the MCL (5 µg/L) in MW-6, MW-7, MW-8, and MW-58B. Total chromium and lead were detected above the MCL in MW-8 in 1986. Lead was also present above the MCL in MW-58B in 1987 sampling. Nickel was detected above the MCL during the 1986 sampling in monitoring wells MW-6, MW-7 and MW-8. However, in the subsequent sampling events, nickel was not analyzed.

Lower Saturated Zone. The chemical quality of the LSZ was determined by sampling the four monitoring wells. Wells MW-6A, and MW-8A were located hydraulically upgradient of

Table 5-8

Frequency of Detected Analytes in Upper Saturated Zone Groundwater SWMU-2, Landfill 5, Tinker AFB

(Page 1 of 2)

Analyte	Frequency of Detection	Range of Detected Concentration	Location of Maximum Concentration
Volatile Organics (µg/L)			
1,1-Dichloroethane	4/16	<5-6	MW-58B
1,2-Dichloroethene (total)	5/11	<5-99	MW-58B
1,4-Dichlorobenzene	3/16	8-<10	MW-58B
2-Butanone	1/15	<10-140	MW-58B
Acetone	5/16	<10-870	MW-6
Benzene	2/16	<0.5-14	MW-58B
Chlorobenzene	3/16	2-<5	MW-58B
Chloroethane	3/16	4-12	MW-6
Chloroform	2/16	<0.5-6.5	MW-7
Dibromochloromethane	1/16	<5-38	MW-6
Ethyl benzene	3/16	<5-16	MW-58B
Isopropylbenzene	1/16	<0.5-5	MW-58B
Methylene chloride	6/16	1-94	MW-58B
2-Methylphenol	1/12	<10-7 J	MW-58B
Naphthalene	2/16	<0.5-5B	MW-58B
Toluene	4/16	0.7-6	MW-58B
Trans-1,2-dichloroethene	5/8	<10-720	MW-6
Trichloroethene	8/16	<5-45	MW-58B
Vinyl chloride	7/16	3-280	MW-6
Xylene (total)	4/16	<5-23	MW-58B
Semivolatile Organics (µg/L)			
4-Methylphenol	2/15	9-11	MW-58B
Benzoic acid	2/14	9-<50	MW-58B
Bis(2-ethylhexyl)phthalate	8/15	10-39	MW-7
Di-n-octyl phthalate	5/15	1-10	MW-6
Diethyl phthalate	5/15	0.4-37	MW-58B

Table 5-8

(Page 2 of 2)

Analyte	Frequency of Detection	Range of Detected Concentration	Location of Maximum Concentration
Dimethyl phthalate	1/15	3-<10	MW-58B
Naphthalene	1/15	1-<10	MW-58B
Phenol	2/15	3-<10	MW-58B
General Chemistry			
pH	12/12	6.79-7.47	MW-8
Sulfate (mg/L)	12/12	3-58	MW-58B
Chloride (mg/L)	12/12	9-210	MW-58B
TOC (mg/L)	9/9	0.849-9.87	MW-58B
Conductivity (µmhos/cm)	12/12	759-1995	MW-58B
Metals (µg/L)			
Arsenic	13/16	<1-27	MW-58B
Barium	16/1	500-4900	MW-7
Cadmium	6/16	<5-13	MW-8
Chromium	5/16	<5-250	MW-8
Lead	8/16	<10-210	MW-8
Mercury	2/16	<0.1-1.1	MW-6
Nickel	6/16	53-430	MW-8
Zinc	9/12	11-1300	MW-8

the site and wells MW-13A and MW-58A were located downgradient of the site. The potentiometric surface has a gradient to the southwest. The contaminants found in the LSZ are similar to those found in the USZ groundwater but generally of lesser concentrations, as is shown in the contaminant summary found in Table 5-7. The frequency, range, and location of maximum concentration are listed in Table 5-9. Water supply well 28, south of the landfill, pumped from the producing zone of the LSZ; this well has been sampled and contamination was not detected in the samples taken. Water supply well 28 was plugged in the beginning stages of the construction of the E-6A TACAMO II Naval Project.

Barium, chromium, and lead were detected above their respective MCLs. Barium was detected above the MCL in MW-6A and MW-13A during 1987 sampling. However, subsequent sampling showed barium below MCL in these wells. Chromium and lead were detected above the MCL in MW-13A in 1987, but chromium and lead concentration in MW-13A have since decreased to near detection limits as shown by the analytical results for 1988 and 1989 samples. Nickel was detected above the MCL in MW-13A during 1987 sampling.

Acetone was detected in MW-6A, MW-13A, and MW-58A in the first sampling round (1987), at levels of 34, 3, and 11 µg/L, respectively. It was not detected in any of the samples in 1988, and was found only in MW-6A in 1989 at 14 µg/L. Acetone is a common laboratory contaminant and does not have any current or proposed MCLs. Trichloroethene was detected above the MCL of 5 µg/L in MW-13A and MW-58A; in MW-13A in 1987 and 1988, concentrations were 6 and 18 µg/L, respectively. In MW-58A in 1987, the trichloroethen concentration was 45 µg/L. In addition, benzene was detected in MW-8A during the 1987 sampling at a concentration above the MCL.

Analytical results for the most recent sampling efforts (November 1992) from both the USZ and the LSZ are presented in Tables 5-6 and 5-7.

A groundwater seep located on the northeast edge of the landfill was found dry during sampling events. Therefore, groundwater samples have not been collected from the seep location. A soil sample was collected from the seep location and the analytical results are included in Table 5-2.

Contaminant Fate and Transport. Future migration of contaminants from the landfill has been reduced due to the construction of a landfill cover to minimize infiltration. The

Table 5-9

Frequency of Detected Analytes in the Lower Saturated Zone Groundwater SWMU-2, Landfill 5, Tinker AFB

(Page 1 of 2)

Analyte	Frequency of Detection	Range of Detected Concentration	Location of Maximum Concentration
Volatile Organics (μg/L)			
Acetone	4/14	3-34	MW-6A
Benzene	3/14	4-19	MW-8A
Chlorobenzene	1/14	<0.05-0.9	MW-58A
Cis-1,2-dichlorobenzene	2/14	<0.5-9	MW-6A
1,2-Dichlorobenzene	1/14	<0.5-0.4	MW-58A
Ethyl benzene	2/14	0.6-<5	MW-58A
Isoproylbenzene	1/14	<0.5-5.0	MW-58A
Methylene chloride	4/14	3-13	MW-8A
Tetrachloroethene	1/14	<0.5-2.0	MW-58A
Toluene	2/14	<5-6	MW-58A
Trans-1,2-dichloroethene	2/4	<5-14	MW-58A
Trichloroethene	6/14	1-45	MW-13A
1,3,5-Trimethylbenzene	1/14	<0.5-6.0	MW-58A
Xylene (Total)	1/12	0.5-<5	MW-58A
Semivolatile Organics (μg/L)			
Benzoic acid	1/12	9-<50	MW-8A
Bis(2-ethylhexyl)phthalate	8/12	3-21	MW-58B
Di-n-octyl phthalate	6/12	3-8	MW-8A
Dimethyl phthalate	3/12	7-18	MW-58A
Naphthalene	2/14	<0.5-2B	MW-6A
Phenol	3/12	4-9	MW-13A
General Chemistry			
pH	12/12	7.01-11.43	MW-6A & MW-58A
Sulfate (mg/L)	11/12	<2-47	MW-58A
Chloride (mg/L)	11/12	<2-100	MW-58A

Table 5-9

(Page 2 of 2)

Analyte	Frequency of Detection	Range of Detected Concentration	Location of Maximum Concentration
Conductivity (µmhos/cm)	10/12	330-1195	MW-13A
TOC (mg/L)	8/8	1.43-9.54	MW-58A
Metals (g/L)			
Arsenic	9/14	<1-26	MW-58A
Barium	12/14	<500-5600	MW-13A
Chromium	9/14	<5-180	MW-13A
Iron	2/2	63-1200	MW-8A
Lead	8/14	<10-80	MW-13A
Manganese	2/2	17-1000	MW-6A
Mercury	1/14	<0.1-0.11	MW-8A
Nickel	4/6	10-120	MW-13A
Selenium	1/14	<0.4-1.1	MW-8A
Zinc	7/10	<5-160	MW-13A

integrity of the landfill cover is extremely important because water entering the landfill trenches will enhance generation of trench water and eventual migration into the USZ.

The USZ water table intersects with two of the landfill trenches and may accelerate contaminant migration from trench water into the USZ water. The USZ water table is below the bottom of the remaining trenches and the soil beneath the trenches has been identified as shale. Therefore, the probability of transport of contaminants from these trenches to the USZ is lower than the trenches that intersect with the USZ. However, this does not completely eliminate the possibility that contaminant transport, both horizontally into soils outside landfill limits and vertically to lower aquifers, may occur from the nonintersecting trenches. The contaminants that were detected in the groundwater are predicted to migrate towards the southwest.

A groundwater seep was found near the site. Soil samples from this seep location contained contamination similar to that detected in the trench waste samples, which suggests that the seep may provide a path for contaminant migration to the surface. However, the seep has been observed to be intermittently active.

Summary. Contamination was found in the solid wastes and leachate in the landfill as well as the USZ and LSZ. The solid waste samples and the soil sample from a suspected seep location contained some organic compounds and heavy metals. Six of the ten detected heavy metals were above background levels found for soils at the base. Contaminants were found above primary drinking water standards (MCLs) in landfill leachate, USZ, and LSZ.

The solid waste samples contained low to moderate levels of organic compounds and heavy metals. The soil sample collected from the seep location exhibited chemical characteristics similar to those of the solid waste samples. Therefore, the seep location may represent a potential pathway for migration of contamination from Landfill 5.

The trench water samples contained similar types of contaminants as found in the solid waste samples. Some heavy metals were found above MCLs. Based on the hydrogeological characteristics of the USZ and the quality and occurrence of trench water, a potential for migration of contamination from trench water into the USZ exists.

The USZ groundwater contained some organic compounds and heavy metals above MCLs. However, there was no significant difference in type and level of contamination between the hydraulically upgradient and downgradient monitoring wells. Both the upgradient and downgradient monitoring wells are installed in very close proximity to the landfill trenches. Abandonment of well MW-8 resulted in two upgradient wells and two downgradient wells monitoring the USZ. An additional monitoring well (downgradient and upgradient) to replace the abandoned well will be necessary to evaluate whether Landfill 5 is a source of contamination in the USZ groundwater.

The LSZ groundwater samples showed the presence of very low levels of organic contaminants and low levels of heavy metals. However, the contaminants were only occasionally discovered in the LSZ. Organic contaminants such as methylene chloride and benzene were found above MCLs in the LSZ. Heavy metals such as barium, chromium, lead, and nickel were also found above MCLs. All heavy metal contamination above MCLs was found in 1987 sampling only, and these metals were found below MCLs in subsequent sampling rounds.

Abandonment of well MW-8A has resulted in only three wells remaining in the LSZ. An additional well to replace the abandoned well will be necessary for adequate evaluation of the possible contribution of Landfill 5 contamination in the LSZ groundwater.

6.0 Potential Receptors

A specific potential human and ecological receptor search has not been performed for Landfill 5. Data are available in the form of chemical analysis of soils and groundwater, and can be used to initiate a potential receptors search. The following sections describe the data available to begin identification of potential receptors.

6.1 Human Receptors

Tinker AFB is situated on a relatively flat expanse of grassland. Prior to the development of the Base, the area was characterized by large tracts of agricultural land. The Base currently occupies approximately 5,000 acres of semi-improved and unimproved grounds that are used for the airfield, golf course, housing area, offices, shops, and other uses characteristic of military installations.

The Garber-Wellington aquifer, which underlies Tinker AFB, is the single most important source of potable groundwater in the Oklahoma City area. The recharge area for the Garber-Wellington aquifer covers the eastern half of Oklahoma County, including Tinker AFB. Approximately 75 percent of the Base's water supply is obtained from production wells pumping from this aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by municipal distribution systems also depend on the Garber-Wellington aquifer. Communities, such as Oklahoma City, presently depending upon surface water supplies also maintain a well system drilled into this aquifer as a standby source of water in the event of drought. Lake Stanley Draper, a local surface water supply reservoir with a small portion of its drainage basin within the boundaries of Tinker AFB, serves a significant recreational function as well.

In 1989, approximately 26,000 military and civilian personnel worked at Tinker AFB. Of these, approximately 2,722 personnel occupied on-Base housing, which consisted of 530 family housing units and seven dormitories. At that time, 1,262 of these residents were children. Military personnel and their families who reside on Base represent the nearest receptors to releases from Tinker AFB.

The current land use at and near the Base is not expected to change because the facilities have decades of useful life remaining and the Base has an important and continuing mission.

However, other future land use scenarios and any human receptors associated with those scenarios may need to be considered.

6.2 Ecological Receptors

Tinker AFB lies within a grassland ecosystem, which is typically composed of grasses, forbes, and riparian (i.e., trees, shrubs, and vines associated with water courses) vegetation. This ecosystem has generally experienced fragmentation and disturbances as result of urbanization and industrialization at and near the Base. While no threatened or endangered plant species occur on the Base, the Oklahoma penstemon (*Penstemon oklahomensis*), identified as a rare plant under the Oklahoma Natural Heritage Inventory Program, thrives in several locations on Base. Tinker AFB policy considers rare species as if they were threatened or endangered and provides the same level of protection for these species.

In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base. However, one specie found on the Base, the Texas horned lizard (*Phrynosoma cornutum*), is a Federal Category 2 candidate specie and under review for consideration to be listed as threatened or endangered. Air Force policy (AFR 126-1) considers candidate species as threatened or endangered and provides the same level of protection.

The Oklahoma Department of Wildlife Conservation also lists several species within the state as Species of Special Concern. Information on these species suggests declining populations but information is inadequate to support listing, and additional monitoring of populations is needed to determine the species status. These species also receive protection by Tinker AFB as threatened or endangered species. Of these species, the Swainson's hawk (*Buteo swainsoni*) and the burrowing owl (*Athene cunicularia*) have been sighted on Tinker AFB. The Swainson hawk, a summer visitor and prairie/meadow inhabitant, has been encountered Basewide. The burrowing owl has been known to inhabit the Air Field at the Base.

7.0 Action Levels

An "action level" is defined by EPA in proposed rule 40 CFR 264.521 (55 FR 30798; 7/27/90), "Corrective Action for Solid Waste Management Units (SWMU) at Hazardous Waste Management Facilities," as a health- and environment-based level, determined by EPA to be an indicator for protection of human health and the environment. In the preamble to this proposed rule, the focus of the RFI phase is defined as "characterizing the actual environmental problems at the facilities." As part of this characterization, a comparison of the contaminant concentrations to certain action levels should be made to determine if a significant release of hazardous constituents has occurred. This comparison is then used to determine if further action or corrective measures are required for a SWMU or an AOC. The preamble to the proposed rule states that the concept of action levels was introduced because of the need for "a trigger that will indicate the need for a Corrective Measures Study (CMS) and below which a CMS would not ordinarily be required" (55 FR 30798; 7/27/90). If constituent concentrations exceed certain action levels at a SWMU or an AOC, further action or a CMS may be warranted; if constituent concentrations are below action levels, a finding of no further action may be warranted. This chapter of the report presents the initial analytical data as compared to certain potential action levels.

Action levels are concentrations of contaminants at or below which exposure to humans or the environment should not produce acute or chronic effects.

The action level information is presented in this chapter so that a constituent concentration at a sample location can be compared with its potential action level. Only constituents identified in the analysis are listed in the SWMU-2, Landfill 5 table. Table 7-1 shows the action levels for soil, water, and air as published in federal or state regulations, policies, guidance documents, or proposed rules. The data included in Table 7-1 is representative of the data presented in Chapter 5.0.

The action levels listed in Table 7-1 are:

- ***SWMU Corrective Action Levels (CAL)*** **-** The first set of action levels provided in the table are those taken from the proposed rule (40 CFR 264.521) and provided as Appendix A to the rule as "Examples of Concentrations Meeting Criteria for Action Levels." These levels are health-risk based and are provided

Table 7-1

Action Levels
SWMU-2, Landfill 5, Tinker AFB

(Page 1 of 2)

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air ($\mu g/m^3$)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air ($\mu g/m^3$)	WQS[e] Water (mg/L)
Organics							
1,2-Dichlorobenzene				0.6			
1,2-Dichloroethane	8.0		0.04	0.005			
1,3-Dichlorobenzene				0.6			
1,4-Dichlorobenzene				0.075			
Acetone	8000	4.0					
Benzene				0.005			0.714
Bis(2-ethylhexyl)phthalate	50	0.003		0.006			
Chlorobenzene	2000	0.7	20	0.1			
Chloroform	100	0.006	0.04	0.1			4.708
Cis-1,2-dichloroethene	8		0.04	0.07			
Di-n-butyl phthalate	8000	4.0					
Diethyl phthalate	60,000	30					
Ethyl benzene	8000	4.0		0.7			28.72
Methylene chloride	90	0.005	0.30	0.005			
Phenol	50,000	20					4615
Tetrachloroethene	10	0.0007	1.0	0.005			
Toluene	20,000	10	7000	1			301.9
Trans-1,2-dichloroethene	8		0.04	0.1			
Trichloroethene	60			0.005			
Vinyl chloride				0.002			
Xylenes (total)	2.00×10^5	70	1000	10			

Table 7-1

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air ($\mu g/m^3$)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air ($\mu g/m^3$)	WQS[e] Water (mg/L)
Inorganics							
Arsenic	80		7.00×10^{-5}	0.05	21		0.0014
Barium	4000		0.4	2	6400		
Cadmium	40		0.0006	0.005			0.0841
Chromium				0.1	110		3.365
Chromium IV	400		9.00×10^{-5}				
Cyanide	2000	0.7		0.2			
Lead				0.015[f]	27	1.5[g]	0.025
Mercury	20			0.002			0.0006
Nickel	2000	0.7		0.1	61		4.583
Selenium				0.05	1.2		
Silver	200						64.62
Zinc					79		

[a]CAL - Corrective Action Levels
[b]MCL - Maximum Contaminant Levels
[c]USGS - United States Geological Survey
[d]NAAQS - National Ambient Air Quality Standards
[e]WQS - Water Quality Standards
[f]Action Level at the Tap
[g]3 Month Average

as specific examples of levels below which corrective action would not be required.

- ***Maximum Contaminant Levels (MCL) -*** These values are provided from 40 CFR Subpart G, Sections 141.60 through 0.63 as promulgated under the Safe Drinking Water Act. These levels are designated for water media only.

- ***USGS Background -*** These values are provided from the USGS report titled "Elemental Composition of Surficial Materials from Central Oklahoma" (USGS, 1991). These values represent the levels of metals which naturally occur in Central Oklahoma soils.

- ***Background -*** These levels are provided where background could be determined. Where available, background concentrations are listed for metals in soil samples taken on site, which were thought to be unaffected by releases from a unit.

- ***National Ambient Air Quality Standards (NAAQS) -*** These standards are published in 40 CFR Part 50 under the Clean Air Act and apply to point sources that emit a limited number of constituents to the air. The constituents regulated are nitrogen dioxide, sulphur dioxide, carbon monoxide, lead, ozone, and particulate matter. Currently, it is assumed that none of the SWMUs or AOCs emit these compounds in regulated quantities and no air samples have been taken which would allow for a valid comparison.

- ***Water Quality Standards (WQS) -*** The WQS are the standards for surface water quality as established by the State of Oklahoma. These standards apply to point source discharges to surface waters and have been listed for those units adjacent to surface water.

8.0 Summary and Conclusions

Landfill 5 is located in the southeast portion of Tinker AFB. The site is bounded by Tower Road on the west, the taxiway to the south and Crutcho Creek to the north and east. Landfill 5 was used from 1968 to 1970 for the disposal of waste. Waste disposed of in the landfill included general refuse with small quantities of industrial waste. The landfill trenches run from northwest to southeast and are approximately 400 feet long, 50 feet wide, and 16 feet deep. Upon closure, the landfill was covered with soil and vegetation.

Four soil borings were installed through landfill trenches to sample the solid waste. In addition, two water samples were taken from water contained in trench borings. Solid waste samples taken from the landfill trenches and the seep location contain concentrations of metals above background levels and some VOCs and SVOCs. The waste was encountered from 3.0 to 7.5 feet below the surface and was 16 to 17 feet in thickness.

Soil contamination found in the seep location is suspected to have originated in Landfill 5. However, other studies conducted in the vicinity of Landfill 5 have concluded that nearby surface water sources are not contaminated.

Groundwater at the Landfill 5 site occurs in three zones: (1) the leachate in the landfill trenches, (2) the USZ, which occurs below the landfill trenches, and (3) the LSZ.

The groundwater found in the landfill trenches was contaminated with cadmium and lead, and with VOCs and SVOCs which were primarily ketones and fuel-related compounds. Vertical migration of the trench water is limited by shale beds at the bottom of the landfill trenches. A total of nine monitoring wells were installed at the landfill to monitor both the USZ and LSZ. Groundwater sampling analysis indicated contaminants found in the USZ and LSZ included heavy metals, and VOCs and SVOCs which are primarily halogenated solvents. The contaminant concentrations were lower in the LSZ than in the USZ.

Of the nine wells originally installed at the site, two wells (MW-8 and MW-8A) no longer exist. These wells were abandoned during construction of the Navy TACAMO taxiway. It was also recognized by Tinker AFB personnel that no true upgradient wells existed for the site. Consequently, a two-well cluster consisting of a USZ and an LSZ well was completed to the northeast of the site in September 1993 to monitor potential migration of contaminants from upgradient areas.

Interim Remedial Actions. Interim corrective measures at the site included:

- Construction of a compacted clay cap in August 1990. The clay cap was constructed to minimize the infiltration of water into the landfill trenches and mitigate the migration of contaminants into the surrounding groundwater. The cap design consisted of a two-layer system. The impermeable layer was designed to be an 18-inch compacted layer of clay with a maximum permeability of 1 x 10^{-7} cm/s. This layer was designed to be protected from erosion by a 12-inch layer of topsoil planted with grass. This cover system was deemed the most appropriate based on freeze-thaw depth, effectiveness in preventing water infiltration, constructability, and cost. Maintenance requirements include mowing of the grass on top of the cap and an annual inspection of the cap to check for damage from erosion, subsidence, etc. Corrective measures for cap damage will include placement of soil in damaged areas and establishing vegetation. The cap covers approximately 5 square acres.

- Design of a system to remove and treat the leachate trapped in landfill trenches. The system will also collect any water that percolates through the cap in the future (USACE, 1992).

- Plugging of water supply well 28 as a part of the E-6A TACAMO II Naval Project to allow construction of the taxiway to the Naval facilities.

9.0 Recommendations

The RI report by USACE (1993b) concluded that the data collected during RI activities was insufficient to make a conclusion regarding the potential contribution of Landfill 5 to contamination in the USZ and LSZ and potential contamination to surface water. Therefore, the following is recommended to enable full definition of the vertical and horizontal extent of contamination at the landfill and to fully meet EPA hazardous waste management permit requirements for the site:

- Evaluate the effectiveness of the cap to minimize infiltration and appropriately channel surface water run off.

- Evaluate the areal extent of the cap and place borings for collection of soil samples outside the limits of the cap (possibly up to six borings with up to three soil samples per boring collected from all sides of the cap and analyzed for metals, VOCs, SVOCs, and inorganic parameters. The soil analytical results are necessary to define the extent of soil contamination, if any, in the immediate vicinity of Landfill 5.

- Perform qualitative evaluation of the potential for human and ecological receptors to become exposed to chemicals associated with the site, including:

    - Evaluation of sources of contamination

    - Evaluation of contaminant release and transport mechanisms

    - Evaluation of potential pathways, under current and future land-use scenarios, by which potential receptors may be exposed to chemicals.

  For this step, the minimum evaluation should include investigation of completed exposure pathways from contamination of groundwater (USZ or LSZ) and from contamination of ambient air. If necessary, this evaluation should be followed by a quantitative estimation of the potential for human exposure (cancer and noncancer risk). The quantitative step should be performed using the most recent EPA guidance, default values for chemical intake variables, and toxicity values. Considerable care should be exercised in the site evaluation, sampling, and data evaluation to ensure that the data used in the risk assessments accurately reflect the contamination present at the site.

- Evaluate the most recent groundwater data (November 1993) with sufficient graphical presentations to determine the current site conditions and to provide recommendations for specific monitoring well locations which may be necessary to further define extent of groundwater contamination.

- Four additional downgradient USZ/LSZ monitoring well clusters should be established to the south, southwest, and west of the site. Additional soil borings may be recommended during the development of the work plan, if necessary, to delineate the extent of contamination in the soils. In addition, one upgradient and two downgradient monitoring wells will be completed to a depth of approximately 150 feet to monitor deeper sections of the LSZ, and will be installed as additions to well clusters 2-21, 13, and 58. Every monitoring well will have a 10-foot screen unless geological conditions require shorter screens. All monitoring well will be added during Phase II of the RFI as part of the basewide groundwater investigation.

- Sample the newly installed upgradient wells MW2-21A and MW2-21B to monitor the USZ and LSZ outside the influence of the landfill and monitor potential contaminant migration from upgradient areas.

- Continue groundwater sampling to monitor contaminant migration and site conditions. Samples should be analyzed for VOCs, SVOCs, metals, and inorganic parameters.

In addition, to fully evaluate the extent of soil contamination at this site it is recommended that site-specific soil background samples be collected during the Phase II RFI. This additional information along with the USGS background values should be used in the Phase II report to distinguish site-related from background concentrations in a statistically significant manner. During the development of the Phase II RFI work plan, the number of background samples to be collected, the location of the soil borings, and the soil analysis to be performed on the samples should be determined for EPA approval.

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Final Report
Phase I RCRA Facility Investigation for Appendix I Sites
VOLUME VII

SWMU-3, Landfill No. 1

Department of the Air Force
Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma

September 1994

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List of Acronyms

AFB	Air Force Base
AOC	area of concern
B&V	B&V Waste Science and Technology Corporation
CAL	corrective action level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/s	centimeters per second
DERP	Defense Environmental Restoration Program
DOD	U.S. Department of Defense
DWS	drinking water standards
EID	Engineering Installation Division
EPA	U.S. Environmental Protection Agency
ES	Engineering Science
ft/ft	foot per foot
HARM	hazardous assessment rating methodology
HSWA	Hazardous and Solid Waste Amendments
HSBZ	Hennessey water bearing zone
IRP	Installation Restoration Program
LSZ	lower saturated zone
µg/kg	micrograms per kilogram
µmhos/cm	micromhos per centimeter
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NPL	National Priorities List
PA/SI	preliminary assessment/site investigation
PCB	polychlorinated biphenyl
pCi/L	picocuries per liter
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RI/FS	remedial investigation/feasibility study
RFI	RCRA Facility Investigation

ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TSD	treatment, storage, and disposal (facility)
TOC	total organic carbon
USACE	U.S. Army Corps of Engineers
USC	U.S. Code
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USZ	upper saturated zone
UWBZ	upper water-bearing zone
VOC	volatile organic compounds
WQS	water quality standard
yd^3	cubic yards

Executive Summary

This report provides a summary of the various investigations that have been conducted at solid waste management unit (SWMU)-3, Landfill No. 1 (Landfill 1), Tinker Air Force Base (AFB), Oklahoma. The report has been prepared to determine and document whether sufficient investigations at Landfill 1 have been performed to meet regulatory requirements. Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County. The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. The Base encompasses approximately 5,000 acres.

Background. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon™, jet fuels, and radium paints.

In 1984, Congress amended the Resource Conservation and Recovery Act (RCRA) with the Hazardous and Solid Waste Amendments (HSWA), which allow the U.S. Environmental Protection Agency (EPA) to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or contaminants from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989, Tinker AFB submitted its Part B permit application for renewal of its operating RCRA Hazardous Waste Storage facility permit. The final RCRA HSWA permit issued on July 1, 1991, requires Tinker AFB to investigate all SWMUs and areas of concern (AOC) and to perform corrective action at those identified as posing a threat to human health or the environment. The permit specifies that a RCRA Facility Investigation (RFI) be conducted for 43 identified SWMUs and two AOCs on the Base. This document has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 1.

Source Description. Landfill 1 was in operation from 1942 to 1945. The landfill received all solid and liquid wastes, including general refuse and industrial wastes, generated at Tinker AFB. The site may have received waste solids from the domestic waste treatment plant (Radian Corporation [Radian], 1985a). The waste was placed in unlined trenches running east to west across the site, and was typically burned to reduce the volume. The trenches extended to a depth of 10 to 25 feet. The waste was covered daily with several inches of soil excavated during the landfill construction. The quantity of waste placed in Landfill 1 is estimated to be approximately 21,780 cubic yards (yd^3) (U.S. Army Corps of Engineers [USACE], 1993).

Landfill 1 was well covered and showed no exposure of the trenches upon completion of closure operations. However, differential settlement within the trenches had resulted in surface depressions that collected precipitation. The ponded water evaporated or percolated through the landfill.

An interim remedial action to construct a 2-acre cap over Landfill 1 was completed in March 1991. A fence was installed around the cap to restrict access to the area and protect the integrity of the landfill cover. The cap was designed to RCRA standards. The purpose of this interim measure was twofold:

- Minimize the migration of contaminated leachate to groundwater via infiltration of rainwater, thereby reducing the mobility of subsurface pollutants.

- Minimize surface soil erosion and landfill maintenance.

This interim measure was deemed to be appropriate, cost-effective, and protective of human health and the environment.

Site Investigations. The initial phase of the investigations conducted at Tinker AFB was conducted by Engineer Science (ES, 1982). The purpose of this study was to conduct a records search for identification of past waste disposal activities to evaluate potential sources of contamination. The investigation found that general refuse placed in Landfill 1 was burned to reduce the volume. Only small amounts of chemicals and industrial waste were suspected of being disposed of in the landfill. ES concluded that Landfill 1 posed a low potential for migration of contaminants. No recommendations were given by ES regarding Landfill 1.

The second phase of investigations was to determine if environmental contamination had occurred due to disposal and management practices at Landfill 1. From 1983 to 1985, Radian was retained to perform these investigations. Activities included an estimate of the magnitude and extent of contamination, the identification of environmental consequences of migrating pollutants, and the recommendation of additional investigations necessary to identify the magnitude, extent, and direction of movement of discovered contaminants.

Before Radian's investigation, five monitoring wells (1 through 5) were installed south of Crutcho Creek. In 1983, Radian installed three additional monitoring wells (1A, 1B, and 1C). One of the Radian monitoring wells (MW-1A) located west of Landfill 1 showed evidence of contaminant migration to deeper strata. This well was renamed by the USACE as MW-9A. Radian's field investigation found that groundwater depths ranged from 4 to 50 feet below the land surface in the area of Landfills 1 through 4. This finding reflected the general topography of the land surface of the area. Water levels were the highest near Crutcho Creek, which borders Landfill 1 to the north and east.

Radian collected sediment samples along Crutcho Creek. One sample was obtained along the creek downstream of Landfill 1. The latter stage of Radian's activities concentrated on areas of contamination identified previously by Radian.

Tinker AFB employed the USACE between 1986 and 1990 to conduct a remedial investigation (RI) of Landfill 1 as part of the U.S. Air Force Installation Restoration Program (IRP). In February 1987, the USACE drilled two soil borings (L1-1 and L1-2) into landfill trenches at Landfill 1. Waste material indicative of general refuse was encountered in both borings. Analytical results of soil and water samples collected from the trench borings indicated contamination from organic compounds and metals.

During the course of the RI, the USACE installed five additional monitoring wells, along with three existing wells, to characterize groundwater around Landfill 1. Four wells were placed in both the upper and lower saturated zones (USZ and LSZ). These wells were sampled during the RI, and continue to be sampled as part of the ongoing groundwater monitoring program for the site.

Soil and groundwater samples collected have been analyzed for volatile organic compounds (VOC), semivolatile organic compounds (SVOC), metals, indicator parameters, pesticides, and PCBs. Groundwater samples were also analyzed for radiometric parameters. An evaluation of the data to establish constituents of potential concern has not been performed. However, contaminant concentrations were compared to health and environment-based action levels. The action levels included SWMU corrective action levels (CAL), maximum contaminant levels (MCL), and water quality standards (WQS) derived from federal and state regulations.

Nine metals were detected in the landfill soils. Cadmium and mercury were the only metals detected at concentrations above naturally occurring background. Both metals were detected at concentrations below action levels. No VOCs, SVOCs, or pesticides and PCBs were detected above action levels.

Methylene chloride was the only organic compound detected above action levels within the groundwater samples collected within the landfill. Twelve metals were detected within landfill water samples. Barium, cadmium, chromium, lead, mercury, and nickel were all detected at concentrations above their respective action limits. In addition, gross alpha activity was measured in water samples at levels above MCLs.

Groundwater samples were collected from monitoring wells 1B, 2A, and 9A, which are completed in the USZ. Sixteen VOCs were detected, but only methylene chloride, trichloroethene, benzene, and vinyl chloride were detected at concentrations exceeding their respective action levels. Bis(2-ethylhexyl)phthlalate was the only SVOC detected above its action level. Twelve metals were detected in USZ groundwater samples. Metals detected above their respective action levels included barium, cadmium, chromium, lead, and nickel. In addition, gross alpha activity was measured at levels slightly above action levels.

Groundwater samples were collected from monitoring wells 2B and 9B, which are completed in the LSZ. Trichloroethene, 1,2-dichloroethene, and bis(2-ethylhexyl)phthalate were the only organic compounds detected above action levels. Seven metals were detected in LSZ groundwater samples. Lead was the only metal detected above its action level. In addition, gross alpha activity was measured at levels exceeding its action limit.

A preliminary comparison was performed of the contaminants detected in the Landfill 1 soils and shallow groundwater versus monitoring wells completed in the USZ and LSZ adjacent to the landfill. The comparison showed that a significant number of the contaminants detected in the USZ and LSZ wells were not detected within the landfill. This comparison suggests that the groundwater in the vicinity of landfill may be impacted by sources other than Landfill 1.

Tinker AFB employed B&V Waste Service Science and Technology (B&V) in 1989 to evaluate alternative cover systems for Landfill 1 and reroute an active sanitary sewer line beyond the limits of the cover system. Based on B&V's recommendation and RCRA-required changes, a final cover design was constructed and completed in March 1991.

The following are recommendations to be implemented during the Phase II RFI:

- A thorough review of the RI summary tables presenting analytical results and the laboratory results should be performed to resolve discrepancies. Not all of the laboratory results were present in the appendices of the RI. These results need to be added for verification of summary table results.

- The effect of the Landfill 1 RCRA cap on the local hydrology should be studied as part of an ongoing monitoring process.

- Install additional groundwater monitoring wells in the HWBZ, USZ, and LSZ to characterize and determine the lateral and vertical extent of groundwater contamination originating from Landfill 1. The wells should be sampled for VOCs, SVOCs, metals, inorganic parameters, and radionuclides.

- Perform aquifer slug tests on selected wells to obtain data to determine groundwater flow rates and evaluate potential migration of contaminants.

- Perform a baseline risk assessment to assess potential impacts to human health and the environment. The assessment should include both human health and ecological assessment.

- Collect site-specific soil background samples to be used in addition to USGS soil data to distinguish site-related from background concentrations in a statistically significant manner.

1.0 Introduction

1.1 Purpose and Scope

This document has been prepared in response to the U.S. Department of the Air Force, Tinker Air Force Base (AFB), Oklahoma request for a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Summary Report for solid waste management unit (SWMU)-3, Landfill No. 1 (Landfill 1).

The objective of this RFI Summary Report is to provide Tinker AFB with one comprehensive report that summarizes the various investigations that have occurred at Landfill 1 since the first environmental investigation was initiated on Base in 1981. The purpose of this comprehensive summary document is to:

- Characterize the site (Environmental Setting).
- Define the source (Source Characterization).
- Define the degree and extent of contamination (Contamination Characterization).
- Identify actual or potential receptors.
- Identify all action levels for the protection of human health and the environment.

Additionally, this document briefly describes the procedures, methods, and results of all previous investigations, remedial actions, and baseline risk assessment that relate to Landfill 1 and contaminant releases, including information on the type and extent of contamination at the site, and actual or potential receptors. Where previous investigations, reports, or studies were not comprehensive and did not furnish the information required to determine the nature and extent of contamination, future work that can be conducted to complete the investigation has been recommended.

1.2 Preface

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to address the cleanup of hazardous waste disposal sites across the country. CERCLA gave the president authority to require responsible parties to remediate the sites or to undertake response actions through use of a fund (the Superfund). The president, through Executive Order 12580, delegated the U.S. Environmental Protection Agency (EPA) with the responsibility to investigate and remediate private party hazardous waste disposal sites that created a threat to human health and the environment. The president delegated responsibility for investigation and cleanup of federal facility disposal sites to the various federal agency heads. The Defense Environmental Restoration Program (DERP) was formally

established by Congress in Title 10 U.S. Code (USC) 2701-2707 and 2810. DERP provides centralized management for the cleanup of U.S. Department of Defense (DOD) hazardous waste sites consistent with the provisions of CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations [CFR] 300), and Executive Order 12580. To support the goals of DERP, the Installation Restoration Program (IRP) was developed to identify, investigate, and clean up contamination at installations.

Under the Air Force IRP, Tinker AFB began a Phase I study similar to a preliminary assessment/site investigation (PA/SI) in 1981 (Engineering Science [ES], 1982). This study helped locate 14 sites that needed further investigation. Phase II studies were performed in 1983 (Radian Corporation [Radian], 1985 a,b).

In 1986, Congress amended CERCLA through SARA. SARA waived sovereign immunity for federal facilities. This act gave EPA authority to oversee the cleanup of federal facilities and to have the final authority for selecting the remedial action at federal facilities placed on the National Priorities List (NPL) if the EPA and the relevant federal agency cannot concur in the selection. Congress also codified DERP (SARA Section 211), establishing a fund for the DOD to remediate its sites because the Superfund is not available for the cleanup of federal facilities. DERP specifies the type of cleanup responses that the fund can be used to address.

In response to SARA, the DOD realigned its IRP to follow the investigation and cleanup stages of the EPA:

- PA/SI
- Remedial investigation/feasibility study (RI/FS)
- Record of Decision (ROD) for selection of a remedial action
- Remedial design/remedial action.

In 1984, Congress amended RCRA with the Hazardous and Solid Waste Amendments (HSWA) which allow the EPA to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or constituents from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989 Tinker AFB submitted its Part B permit application for renewal of its operating RCRA hazardous waste storage facility permit.

EPA, in the Hazardous Waste Management Permit for Tinker AFB, dated July 1, 1991, identified 43 SWMUs and two areas of concern (AOC) on Tinker AFB that need to be addressed. This permit requires Tinker AFB to investigate all SWMUs and AOCs and to perform corrective action at those identified as posing a threat to human health or the environment. This RFI Summary Report has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 1 and to document all determinations.

1.3 Facility Description

Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County (Figure 1-1) with its approximate geographic center located at 35^{o} 25' latitude and 97^{o} 24' longitude (U.S. Geological Survey [USGS], 1978). The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. An additional area east of the main Base is used by the Engineering Installation Division (EID) and is known as Area D. The Base encompasses approximately 5,000 acres. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon^{TM}, jet fuels, and radium paints. Wastes that are currently generated are managed at two permitted hazardous waste storage facilities. However, prior to enactment of RCRA, industrial wastes were discharged into unlined landfills and waste pits, streams, sewers, and ponds. Past releases from these landfills, pits, etc., as well as from underground tanks, have occurred. As a result, there are numerous sites of soil, groundwater, and surface water contamination on the Base.

The various reports generated as a result of investigative activities conducted at Landfill 1 have been reviewed and evaluated in terms of the sites' status under RCRA regulations. A summary based on the review of these reports for Landfill 1 is presented in the following chapters and sections. In addition, recommendations for additional work is given at the end of the summary report.

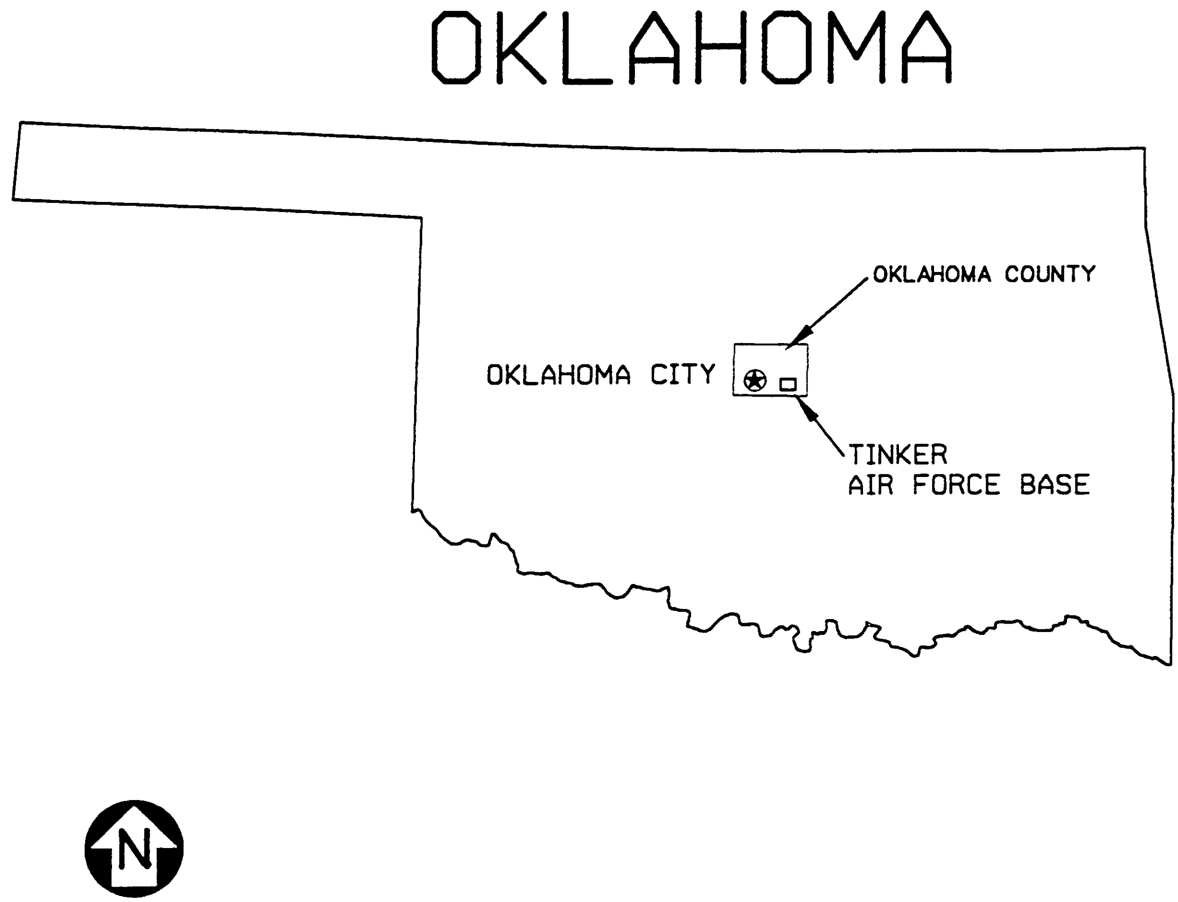

FIGURE 1-1
TINKER AIR FORCE BASE
OKLAHOMA
STATE INDEX MAP

PREPARED FOR
TINKER AFB
OKLAHOMA

STARTING DATE: 03/17/94	DATE LAST REV.:	DRAFT. CHCK. BY:G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY:P.O. TERRY	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.:J. TAYLOR	PROJ. NO.:

3/23/94 POT
FILENAME: G:\TINKER\40983202.075

1.4 Site Description

Landfill 1 is the smallest of the four landfills (Landfills No. 1 through 4 [SWMUs 3 through 6]) located in the southwest corner of the Base. The landfill has a surface area of approximately 1.5 acres and is bordered by Crutcho Creek to the north and east, Patrol Road to the west, and the Building 1022 area to the south. A buried sanitary sewer line intersected the southeast portion of the landfill prior to the construction of a cover system. The sewer line was rerouted beyond the limits of the cover system which was completed in March 1991. The location of Landfill 1 relative to the Base is shown in Figure 1-2.

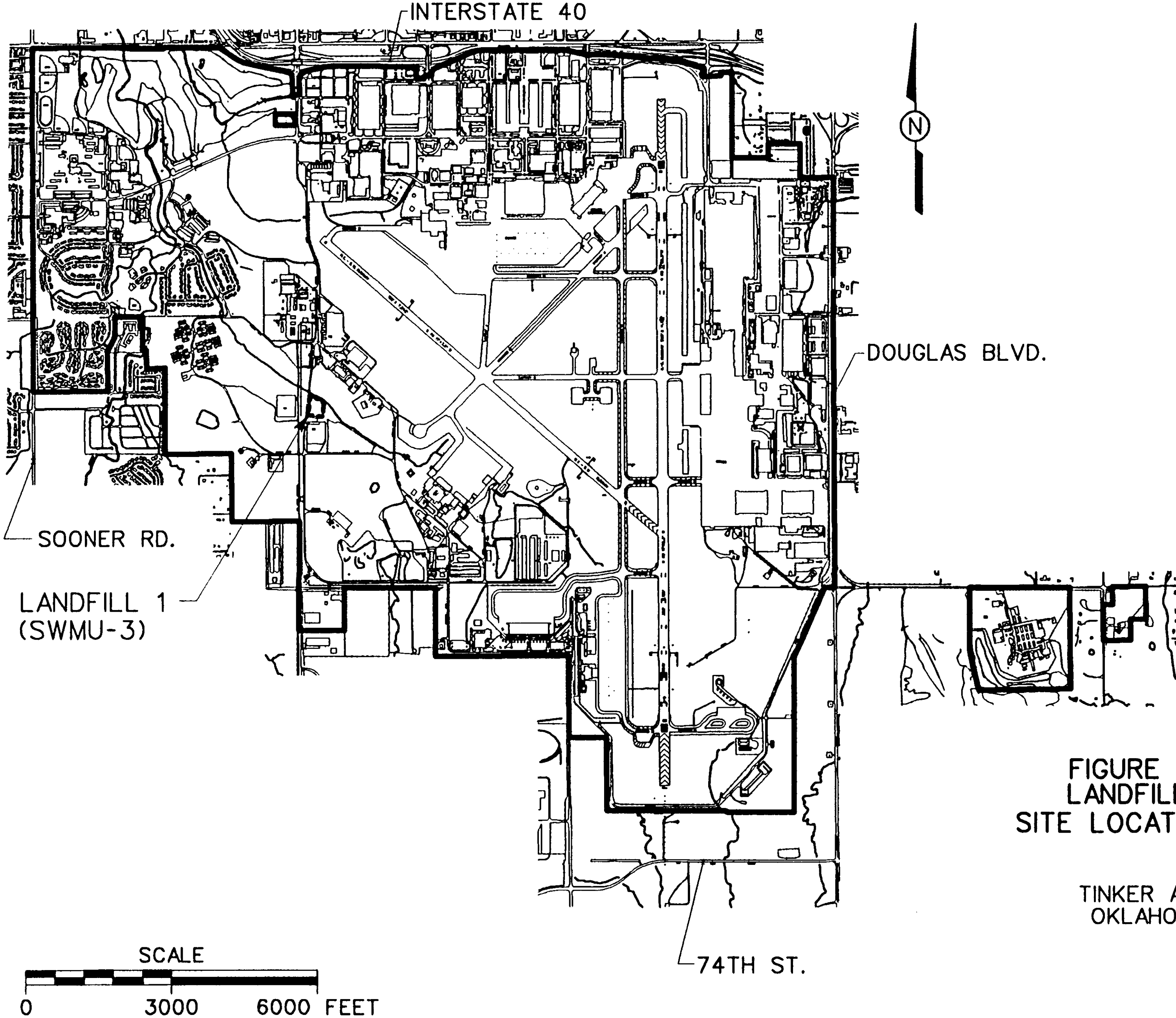

FIGURE 1-2
LANDFILL 1
SITE LOCATION MAP

TINKER AFB
OKLAHOMA

STARTING DATE: 3/21/94	DATE LAST REV.:	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P.O. TERRY	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

FILENAME: G:\TINKER\40983202.081

2.0 Background

2.1 Site Operations and History

Tinker AFB was originally known as the Midwest Air Depot and began operations in July 1941. The site was activated March 1942. During World War II, the depot was responsible for reconditioning, modifying, and modernizing aircraft, vehicles, and equipment.

General refuse generated from Base operations has been disposed of in at least six landfills located on the Base property or leased land adjacent to the Base. One of these landfills, Landfill 1, is located in the southwest corner of the Base.

Landfill 1 was operated from 1942 to 1945 at Tinker AFB. The landfill received all solid and liquid wastes, including general refuse and industrial wastes, generated at Tinker AFB, which was then called Tinker Field. The site may have received waste solids from the domestic wastewater treatment plan (Radian, 1985a). The waste was placed in unlined trenches running east to west across the site, and was typically burned to reduce the volume. The trenches extended to a depth of 10 to 25 feet, though 6- to 8-foot clay layer into a sand/rock zone. The waste was covered daily with several inches of soil excavated during the landfill construction. The quantity of waste placed in Landfill 1 is estimated to be approximately 21,780 cubic yards (yd^3) (U.S. Army Corps of Engineers [USACE], 1993).

Landfill 1 was well covered and showed no exposure of the trenches during closure operations. However, differential settlement within the trenches had resulted in surface depressions that collected precipitation. The ponded water evaporated or percolated through the landfill.

A cover system was constructed for the landfill as an interim remedial action to reduce surface water infiltration. The cover was completed in March 1991.

2.2 Summary of Previous Investigations

Engineering Science, Inc. Landfill 1 was among 14 sites identified for the Phase I studies for the Tinker AFB IRP. The studies were completed by ES in April 1982 (ES, 1982). The Phase I study conducted a records search for the identification of past waste disposal activities to evaluate potential sources of contamination.

ES concluded that Landfill 1 posed a low potential for migration of contaminants and received a hazard assessment rating methodology (HARM) score of 45. The Phase I investigation found that the general refuse placed in Landfill 1 was burned to reduce the volume. Only small amounts of chemicals and industrial waste were suspected of being disposed of in the landfill. No recommendations were given by ES regarding Landfill 1.

Radian Corporation. IRP Phase II, Stage 1 field activities were initiated in 1983 by Radian (1985a). The investigation was conducted to determine if any environmental contamination had resulted from waste disposal practices at Tinker AFB. In addition, the investigation was performed to estimate the magnitude and extent of contamination, to identify environmental consequences of migrating pollutants, and to recommend additional assessment activities to identify the extent and direction of movement of the discovered contaminants.

As part of the Stage 1 investigation, Radian installed three monitoring wells (1-A, 1-B, and 1-C) in the vicinity of Landfills 1 and 4. These wells, along with existing monitoring wells 1 through 5 located south of Crutcho Creek and northeast of Landfills 1, 2, and 3, indicated that the depth to groundwater ranged from 4 to 50 feet below the ground surface in the vicinity of the landfills. This finding either reflects the general topography in the area of Landfills 1 through 4 or the presence of multiple saturated zones penetrated by wells screened at different depths. Water levels were highest near Crutcho Creek, which borders Landfill 1 to the north and east.

One of the three Radian monitoring wells, MW-1A, was located west of Landfill 1. According to Radian's report, this well showed evidence of contaminant migration to deeper strata. This well was later renamed as MW-9A by the USACE. The location of this well is shown in Figure 2-1.

Radian's Phase II, Stage 2 (Radian, 1985b) field activities conducted from June through October 1984 focused on areas of contamination discovered during the Phase II, Stage 1 field work, and did not involve any additional groundwater testing or soil borings at Landfill 1. Radian did collect sediment samples along Crutcho Creek sediment. Sample No. 9 was obtained along the creek downstream of Landfill 1, but no elevated levels of industrial contaminants were detected.

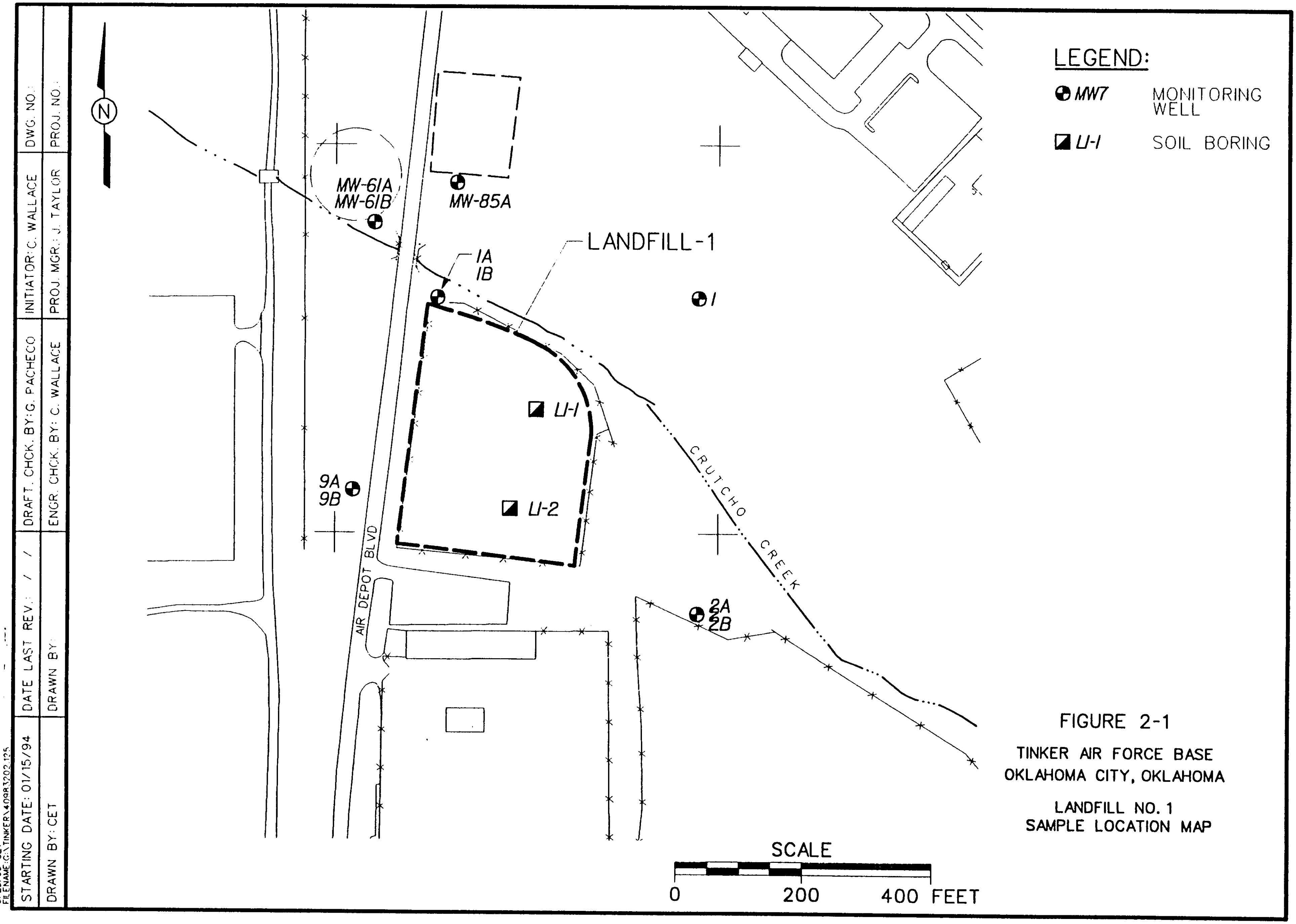

FIGURE 2-1
TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA
LANDFILL NO. 1
SAMPLE LOCATION MAP

U.S. Army Corps of Engineers. Tinker AFB employed the USACE between 1986 and 1990 to conduct an RI of Landfill 1 as part of the U.S. Air Force IRP. The USACE assessed the magnitude and extent of contamination originating in the Landfill 1 trenches. USACE investigations included records searches, subsurface geologic explorations, installation and sampling at monitoring wells and two soil borings (L1-1 and L1-2), sampling of water and solid wastes from the Landfill 1 trenches, explorations to estimate the volume of refuse in the trenches, and specific-use dump area investigations. The locations of soil borings and monitoring wells adjacent to Landfill 1 are shown in Figure 2-1.

During the course of the RI, the USACE installed five additional monitoring wells (MW-1B, 2-B, 9-B, 61-A, and 61-B) in the general vicinity of Landfill 1. In April and May 1986, perimeter wells were installed along the southwest perimeter of the Base to monitor for potential contamination. Three of the perimeter well clusters (MW-45A, 45-B; 46-A, 46-B; and 47-A, 47-B) are in the vicinity of the Landfills 1 through 4 area.

From the three well pairs installed directly around Landfill 1 (MW-1A, 1-B; 2-A, 2-B; and 9-A, 9-B), the USACE concluded that the water within the Landfill 1 trenches is hydraulically connected to a perched water zone and Crutcho Creek. Groundwater flow within this zone was interpreted to be towards the south and southwest in the Landfills 1 through 4 area due to a local topographic high at Landfill 3. The perched zone has more recently been interpreted as the Hennessey water bearing zone (HWBZ). For the purpose of this report, the HWBZ is considered a part of the USZ as discussed in detail in Section 3.3.

Soil borings L1-1 and L1-2 were installed within the Landfill 1 boundary in February 1987. Shelby tube samples were collected from the soil cover for physical characterization. Composite samples of the waste materials encountered in the Landfill 1 trenches were collected for characterization of wastes. Polyvinyl chloride (PVC) pipes were installed in both boreholes to allow for collection of water samples and water elevation data. A soil cover over Landfill 1 was completed in March 1991 as an interim remedial action to reduce the surface water infiltration.

B&V Waste Science and Technology Corporation. Tinker AFB employed B&V in 1989 to evaluate alternative cover systems for Landfill 1 and to reroute the active sanitary sewer beyond the limits of the cover system. B&V recommended a natural soil cover with synthetic water barrier and gas control layer. This alternative was the least expensive of the eight alternative cover systems evaluated (B&V, 1989).

In the summer of 1990, B&V issued a design analysis report and construction specifications for the recommended cover at Landfill 1 (B&V, 1990 a,b). In January 1989, the EPA determined that the landfill would be included in a Part B, RCRA permit because of the HSWA. RCRA-required changes were incorporated, resulting in a design consisting of:

- Six inches of top soil for the vegetative layer
- Eighteen inches of fill material above the drainage layer
- Drainage layer consisting of filter fabric and geogrid drainage material
- Twenty-four-inch clay layer with a permeability of no more than 1×10^{-7} centimeter per second (cm/s) beneath a 40-millimeter flexible membrane liner
- Fill material above present the existing landfill surface to provide a slope of 3 to 5 percent on the cover surface.

Roy F. Weston, Inc. Tinker AFB employed Weston to perform long-term monitoring of groundwater monitoring wells at the site in 1992. The data has been included in the monitoring well data summary tables presented in Chapter 5.0 of this report. A program of long-term groundwater monitoring is presently ongoing at the facility, and the data set is currently being evaluated by Tinker AFB (Weston, 1993).

2.3 Current Regulatory Status

The IRP has been ongoing at Tinker AFB since the early 1980s. IRP studies on the Base were conducted according to IRP guidance, which is essentially the same as EPA's guidance for conducting an RI/FS under CERCLA. All investigations and removal actions have been closely monitored and approved by the EPA.

Since receiving the Hazardous Waste Management Permit on July 1, 1991, many of the IRP sites have come under the jurisdiction of the RCRA permits branch of the EPA. As such, they have been identified as SWMUs; however, a large amount of work has already been performed at most of these sites under the IRP. Additional investigation at the landfills will be performed under the IRP.

3.0 Environmental Setting

3.1 Topography and Drainage

3.1.1 Topography

Regional/Tinker AFB. The topography of Oklahoma City and surrounding area varies from generally level to gently rolling in appearance. Local relief is primarily the result of dissection by erosional activity or stream channel development. At Oklahoma City, surface elevations are typically in the range of 1,070 to 1,400 feet mean sea level (msl). At Tinker AFB, ground surface elevations vary from 1,190 feet msl near the northwest corner where Crutcho Creek intersects the Base boundary to approximately 1,320 feet msl at Area D (EID).

Site. Landfill 1 is located on the southwest corner of Tinker AFB. From the geologic logs (USACE, 1993), the general surface elevation of the landfill was reported to be approximately 1,221 feet msl. An interim remedial action to construct a 2-acre cap over the landfill was completed in March 1991. The cap was designed to RCRA standards.

3.1.2 Surface Drainage

Regional/Tinker AFB. Drainage of Tinker AFB land areas is accomplished by overland flow of runoff to diversion structures and then to area surface streams, which flow intermittently. The northeast portion of the Base is drained primarily by unnamed tributaries of Soldier Creek, which is itself a tributary of Crutcho Creek. The north and west sections of the Base, including the main instrument runway, drain to Crutcho Creek, a tributary of the North Canadian River. Two small unnamed intermittent streams crossing installation boundaries south of the main instrument runway generally do not receive significant quantities of Base runoff due to site grading designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

Site. Surface drainage at Landfill 1 is influenced by the engineered landfill cover in place at the site. The cover was designed to divert surface drainage away from the landfill and to minimize infiltration of precipitation into the landfill. Surface water runoff discharges to Crutcho Creek, which runs to the north and east of Landfill 1.

3.2 Geology

3.2.1 Regional/Tinker AFB Geology

Tinker AFB is located within the Central Redbed Plain Section of the Central Lowland physiographic province, which is tectonically stable. No major fault or fracture zones have been mapped near Tinker AFB. The major lithologic units in the area of the Base are relatively flat-lying and have a regional westward dip of about 0.0076 foot per foot (ft/ft) (Bingham and Moore, 1975).

Geologic formations that underlie Tinker AFB include, from oldest to youngest, the Wellington Formation, Garber Sandstone, and the Hennessey Group; all are Permian in age.

All geologic units immediately underlying Tinker AFB are sedimentary in origin. The Garber Sandstone and Wellington Formation are commonly referred to as the Garber-Wellington Formation due to strong lithologic similarities. These formations are characterized by fine-grained, calcareously-cemented sandstones interbedded with shale. The Hennessey Group consists of the Fairmont Shale and the Kingman Siltstone. It overlies the Garber-Wellington Formation along the eastern portion of Cleveland and Oklahoma counties. Quaternary alluvium is found in many undisturbed streambeds and channels located within the area.

Stratigraphy. Tinker AFB lies atop a sedimentary rock column composed of strata that ranges in age from Cambrian to Permian above a Precambrian igneous basement. Quaternary alluvium and terrace deposits can be found overlying bedrock in and near present-day stream valleys. At Tinker AFB, Quaternary deposits consist of unconsolidated weathered bedrock, fill material, wind-blown sand, and interfingering lenses of sand, silt, clay, and gravel of fluvial origin. The terrace deposits are exposed where stream valleys have downcut through older strata and have left them topographically above present-day deposits. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

Subsurface (bedrock) geologic units which outcrop at Tinker AFB and are important to understanding groundwater and contaminant concerns at the Base consist of, in descending order, the Hennessey Group, the Garber Sandstone, and the Wellington Formation (Table 3-1). These bedrock units were deposited during the Permian Age (230 to 280 million years ago) and are typical of redbed deposits formed during that period. They are composed of a conformable sequence of sandstones, siltstones, and shales. Individual beds are lenticular and vary in thickness over short horizontal distances. Because lithologies are similar and because

Table 3-1

Major Geologic Units in the Vicinity of Tinker AFB (Modified from Wood and Burton, 1968)

(Page 1 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	PLEISTOCENE	Alluvium	0-70	Unconsolidated and interfingering lenses of sand, silt, clay, and gravel in the flood plains and channels of stream	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines.
	AND RECENT	Terrace deposits	0-100	Unconsolidated and interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above the flood plains of the principal streams.	Moderately permeable. Locally above the water table and not saturated. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

Table 3-1

(Page 2 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
PERMIAN	LOWER PERMIAN	Hennessey Group (includes Kingman Siltstone and Fairmont Shale)	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places water contains large amounts of sulfate.
		Garber Sandstone	500±	Deep-red clay to reddish-orange, massive and cross-bedded fine-grained sandstone interbedded and interfingered with red shale and siltstone	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

of a lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are often informally lumped together as the Garber-Wellington Formation. Together, they are about 900 feet thick at Tinker AFB. The interconnected, lenticular nature of sandstones within the sequence forms complex pathways for groundwater movement.

The surficial geology of the north section of the Base is dominated by the Garber Sandstone, which outcrops across a broad area of Oklahoma County. Generally, the Garber outcrop is covered by a veneer of soil and/or alluvium up to 20 feet thick. To the south, the Garber Sandstone is overlain by outcropping strata of the Hennessey Group, including the Kingman Siltstone and the Fairmont Shale (Bingham and Moore, 1975). Drilling information obtained as a result of geotechnical investigations and monitoring well installation confirms the presence of these units.

Depositional Environment. The Permian-age strata presently exposed at the surface in central Oklahoma were deposited along a low-lying north-south oriented coastline. Land features included meandering to braided sediment-loaded streams that flowed generally westward from highlands to the east (ancestral Ozarks). Sand dunes were common, as were cut-off stream segments that rapidly evaporated. The climate was arid and vegetation sparse. Off shore the sea was shallow and deepened gradually to the west. The shoreline's position varied over a wide range. Isolated evaporitic basins frequently formed as the shoreline shifted.

Across Oklahoma, this depositional environment resulted in an interfingering collage of fluviatile and wind-blown sands, clays, shallow marine shales, and evaporite deposits. The overloaded streams and evaporitic basins acted as sumps for heavy metals such as iron, chromium, lead, and barium. Oxidation of iron in the arid climate resulted in the reddish color of many of the sediments. Erosion and chemical breakdown of granitic rocks from the highlands resulted in extensive clay deposits. Evaporite minerals such as anhydrite ($CaSO_4$), barite ($BaSO_4$), and gypsum ($CaSO_4 \bullet 2H_2O$) are common.

Around Tinker AFB, the Hennessey Group represents deposition in a tidal flat environment cut by shallow, narrow channels. The Hennessey Group is comprised predominantly of red shales which contain thin beds of sandstone (less than 10 feet thick) and siltstone. In outcrop, "mudball" conglomerates, burrow surfaces, and dessication cracks are recognized. These units

outcrop over roughly the southern half of the Base, thickening to approximately 70 feet in the southwest from their erosional edge (zero thickness) across the central part of Tinker AFB.

In contrast, the Garber Sandstone and the Wellington Formation around Tinker AFB consist of an irregularly-interbedded system of lenticular sandstones, siltstones, and shales deposited either in meandering streams in the upper reaches of a delta or in a braided stream environment. Outcrop units north of Tinker AFB exhibit many small to medium channels with cut and fill geometries consistent with a stream setting. Sandstones are typically cross-bedded. Individual beds range in thickness from a few inches to approximately 50 feet and appear massive, but thicker units are often formed from a series of "stacked" thinner beds. Geophysical and lithologic well logs indicate that from 65 to 75 percent of the Garber Sandstone and the Wellington Formation are composed of sandstone at Tinker AFB. The percentage of sandstone in the section decreases to the north, south, and west of the Base. These sandstones are typically fine to very fine grained, friable, and poorly cemented. However, where sandstone is cemented by red muds or by secondary carbonate or iron cements, local thin "hard" intervals exist along disconformities at the base of sandstone beds. Shales are described as ranging from clayey to sandy, are generally discontinuous, and range in thickness from a few inches to approximately 40 feet.

Stratigraphic Correlation. Correlation of geologic units is difficult due to the discontinuous nature of the sandstone and shale beds. However, cross-sections (Figure 3-1) demonstrate that two stratigraphic intervals can be correlated over large sections of the Base in the conceptual model. These intervals are represented on geologic cross-sections A-A' and B-B' (Figures 3-2 and 3-3). Section A-A' is roughly a dip section and B-B' is approximately a strike section. The first correlatable interval is marked by the base of the Hennessey Group and the first sandstone at the top of the Garber Sandstone. This interval is mappable over the southern half of Tinker AFB. The second interval consists of a shale zone within the Garber Sandstone which, in places, is comprised of a single shale layer and, in other places, of multiple shale layers. This interval is more continuous than other shale intervals and in cross-sections appears mappable over a large part of the Base. It is extrapolated under the central portion of Tinker AFB where little well controls exists.

Structure. Tinker AFB lies within a tectonically stable area; no major near-surface faults or fracture zones have been mapped near the Base. Most of the consolidated rock units of the Oklahoma City area dip westward at a low angle. A regional dip of 0.0057 to 0.0076 ft/ft in

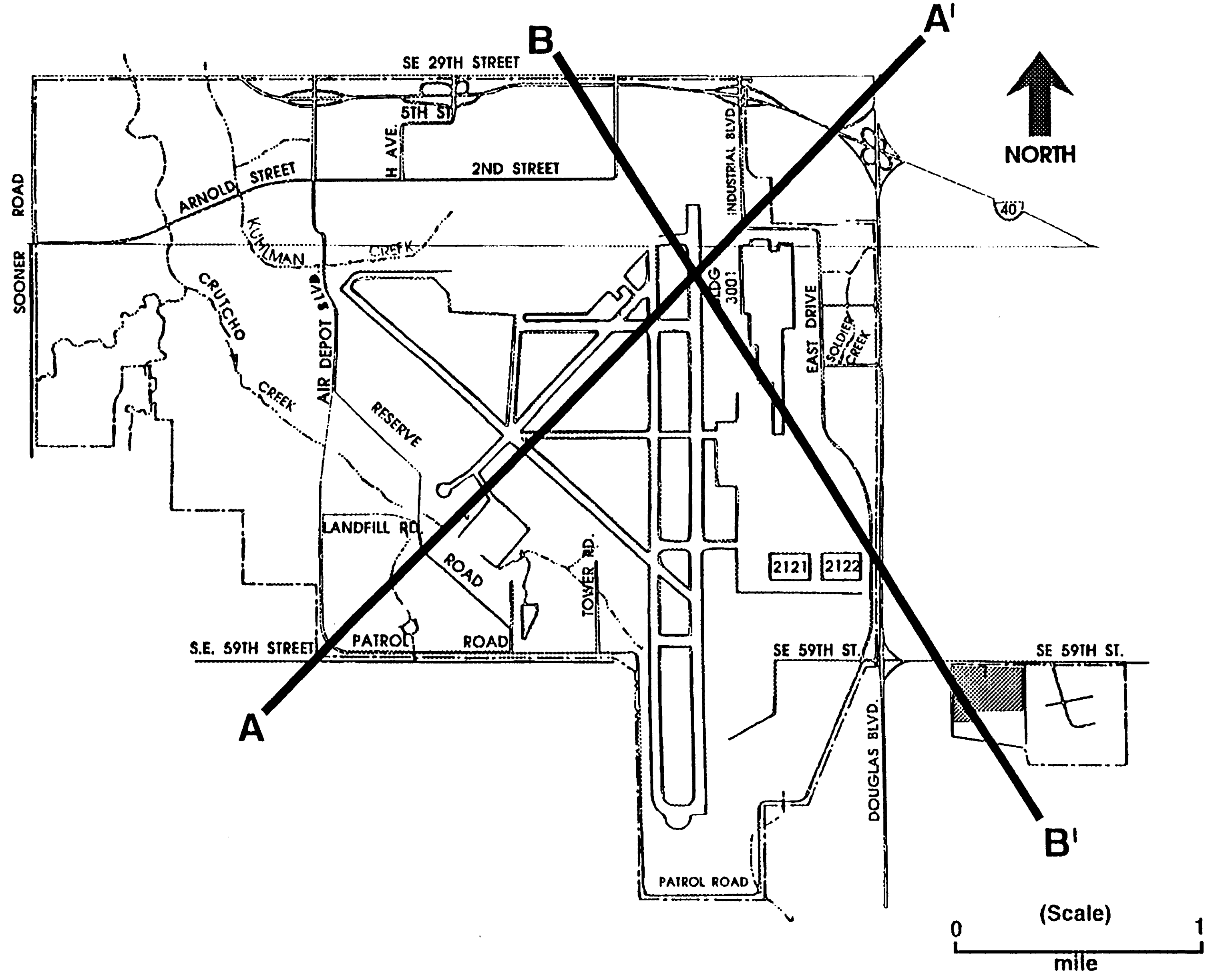

FIGURE 3-1 TINKER AFB GEOLOGIC CROSS SECTION LOCATION MAP

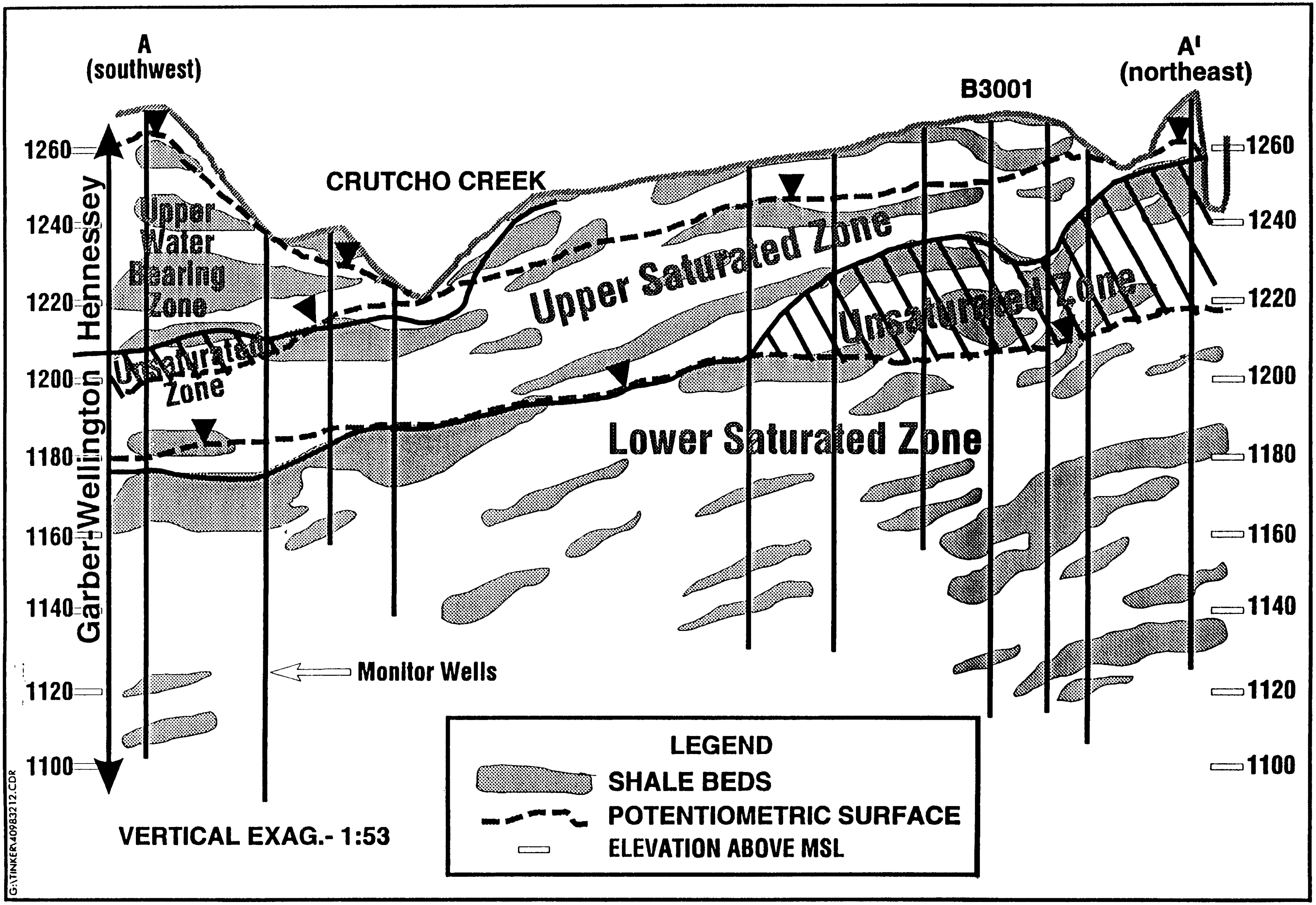

FIGURE 3-2 TINKER AFB GEOLOGIC CROSS SECTION A-A'

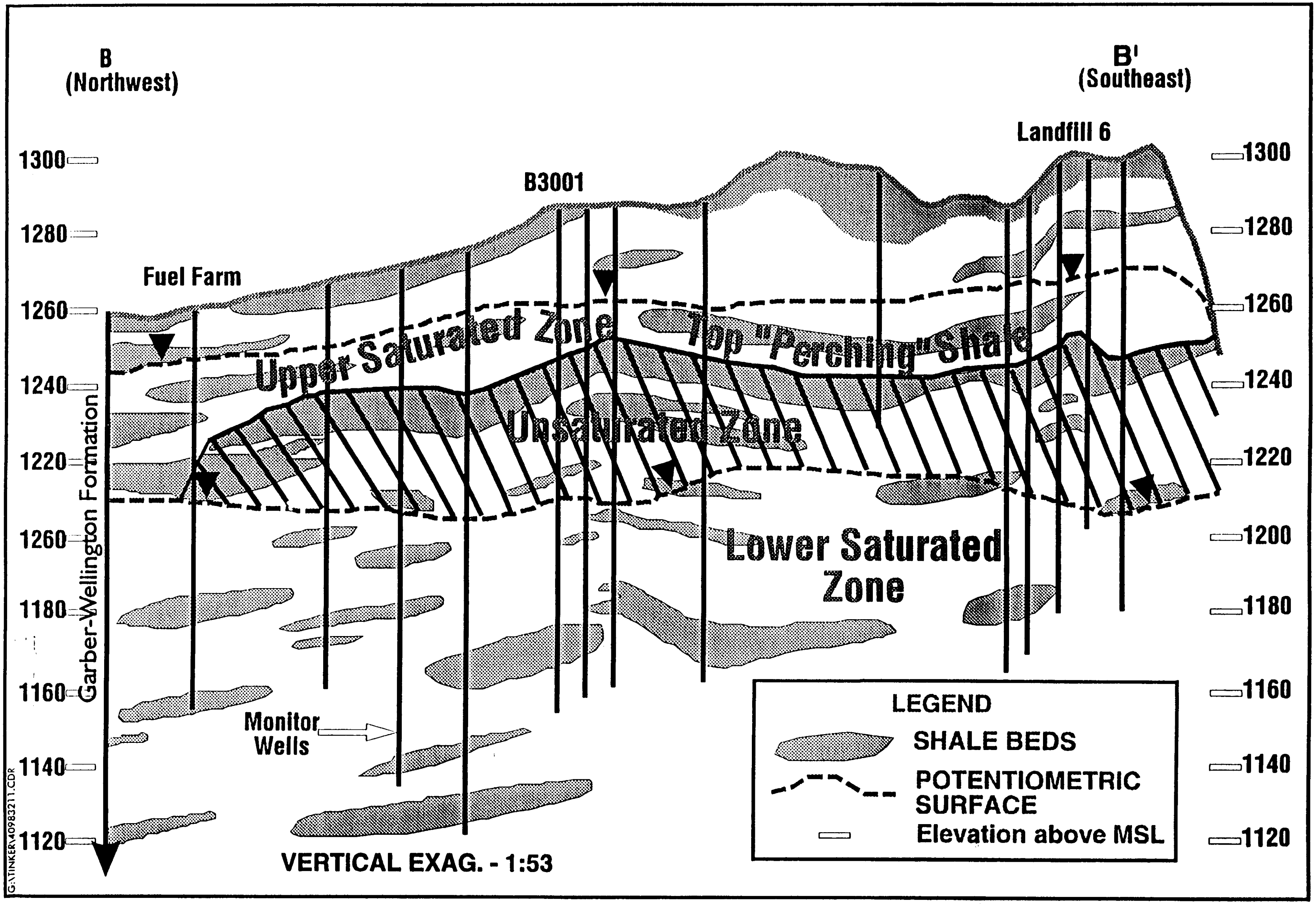

FIGURE 3-3 TINKER AFB GEOLOGIC CROSS SECTION B-B'

a generally westward direction is supported by stratigraphic correlation on geologic cross-sections at Tinker AFB. Bedrock units strike slightly west of north.

Although Tinker AFB lies in a tectonically stable area, regional dips are interrupted by buried structural features located west of the Base. A published east-to-west generalized geologic cross-section, which includes Tinker AFB, supports the existence of a northwest-trending structural trough or syncline located near the western margin of the base. The syncline is mapped adjacent to and just east of a faulted anticlinal structure located beneath the Oklahoma City Oil Field. The fault does not appear to offset Permian-age strata. There are indications that the syncline may act as a "sink" for some regional groundwater (southwest flow) at Tinker AFB before it continues to more distant discharge points.

3.2.2 Site Geology

Landfill 1 is located just south of the contact between the Hennessey Group and the Garber-Wellington Formation. Alluvial deposits (sands, silts, and clays) of varying thickness exist in the shallow subsurface of the Landfill 1 area, extending from the surface down to a depth ranging from 5 to 15 feet below grade. These fine-grained materials exist below the portions of the landfill trenches where the Hennessey shale is nonexistent. During the RI (USACE, 1993), wastes were discovered in the trench areas just below the cover material and ranged in thickness from a few feet to 18 feet before shale was encountered. An 18.5-foot-thick layer of sand described in the drilling log of boring L1-1 (Figure 1-2) as clayey, fine to very fine, medium dense, red and moist existed beneath the trenches of landfill.

3.3 Hydrology

3.3.1 Regional/Tinker AFB Hydrology

The most important source of potable groundwater in the Oklahoma City metropolitan area is the Central Oklahoma aquifer system. This aquifer extends under much of central Oklahoma and includes water in the Garber Sandstone and Wellington Formation, the overlying alluvium and terrace deposits, and the underlying Chase, Council Grove, and Admire Groups. The Garber Sandstone and the Wellington Formation portion of the Central Oklahoma aquifer system is commonly referred to as the "Garber-Wellington aquifer" and is considered to be a single aquifer because these units were deposited under similar conditions and because many of the best producing wells are completed in this zone. On a regional scale, the aquifer is confined above by the less permeable Hennessey Group and below by the Late Pennsylvanian Vanoss Group.

Tinker AFB lies within the limits of the Garber-Wellington Groundwater Basin. Currently, Tinker derives most of its water supply from this aquifer and supplements the supply by purchasing from the Oklahoma City Water Department. The nearby communities of Midwest City and Del City derive water supplies from both surface sources and wells tapping the aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by a municipal distribution system also depend on the Garber-Wellington aquifer. Communities presently depending upon surface supplies (such as Oklahoma City) also maintain a well system drilled into the Garber-Wellington as a standby source of water in the event of drought.

Recharge of the Garber-Wellington aquifer is accomplished principally by percolation of surface waters crossing the area of outcrop and by rainfall infiltration in this same area. Because most of Tinker AFB is located in an aquifer outcrop area, the Base is considered to be situated in a recharge zone.

According to Wood and Burton (1968) and Wickersham (1979), the quality of groundwater derived from the Garber-Wellington aquifer is generally good, although wide variations in the concentrations of some constituents are known to occur. Wells drilled to excessive depths may encounter a saline zone, generally greater than 900 feet below ground surface. Wells drilled to such depths or those accidentally encountering the saline zone are either grouted over the lowest screens or may be abandoned.

Tinker AFB presently obtains its water supplies from a distribution system comprised of 29 water wells constructed along the east and west Base boundaries and by purchase from the Oklahoma City Water Department. All Base wells are finished into the Garber-Wellington aquifer. Base wells range from 700 to 900 feet in finished depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones with a combined thickness from 103 to 184 feet (Wickersham, 1979).

Although the variability in the geology and the recharge system at Tinker AFB makes it difficult to predict local flow paths, Central Oklahoma aquifer water table data show that regional groundwater flow under Tinker varies from west-northwest to southwest, depending on location. This theory is supported by contoured potentiometric data from base monitoring wells which show groundwater movement in the upper and lower aquifer zones to generally follow regional dip. Measured normal to potentiometric contours, groundwater flow gradients

range from 0.0019 to 0.0057 ft/ft. However, because flow in the near-surface portions of the aquifer at Tinker AFB is strongly influenced by topography, local stream base-levels, complex subsurface geology, and location in a recharge area, both direction and magnitude of ground-water movement is highly variable. The interaction of these factors not only influences regional flow but gives rise to complicated local, often transient, flow patterns at individual sites.

As a result of ongoing environmental investigations and the approximately 450 groundwater monitoring wells installed on the Base during various investigations, a better understanding of the specific hydrological framework has emerged. The current conceptual model developed by Tinker AFB (Tinker, 1993), based on the increased understanding of the hydrological framework, has been revised from an earlier model adopted by the USACE. Previous studies reported that groundwater was divided into four water-bearing zones: the perched aquifer, the top of regional aquifer, the regional aquifer, and the producing zone. In the current model, two principal water table aquifer zones and a third less extensive zone have been identified. The third is limited to the southwest quadrant. The third aquifer zone consisted of saturated siltstone and thin sandstone beds in the Hennessey Shale and equates to the upper water bearing zone (UWBZ) described by the USACE (1993) at Landfills 1 through 4 (Landfills 1 through 4). In addition, numerous shallow, thin saturated beds of siltstone and sandstone exist throughout the Base. These are of limited areal extent and are often perched.

In the current conceptual hydrologic model, an upper saturated zone (USZ) and a lower saturated zone (LSZ) are recognized in the interval from ground surface to approximately 200 feet. Below this is found the producing zone from which the Base draws much of its water supply. Figure 3-4 shows the potentiometric surface for the USZ and Figure 3-5 shows the potentiometric surface for the LSZ. The USZ exists mainly under water table (unconfined) conditions, but may be partially confined locally. Conditions in the LSZ are difficult to determine due to screen placement and overly long sandpacks below the screen interval.

The USZ is found at a depth of 5 to 70 feet below ground surface and has a saturated thickness ranging from less than 1 foot at its eastern boundary to over 20 feet in places west of Building 3001. The USZ is erosionally truncated by Soldier Creek along the northeastern margin of Tinker AFB. This aquifer zone is considered to be a perched aquifer over the eastern one-third of Tinker AFB, where it is separated from the LSZ by an underlying confining shale layer and a vadose zone. The confining interval extends across the entire Base, but the vadose zone exists over the eastern one-third of this area. The available

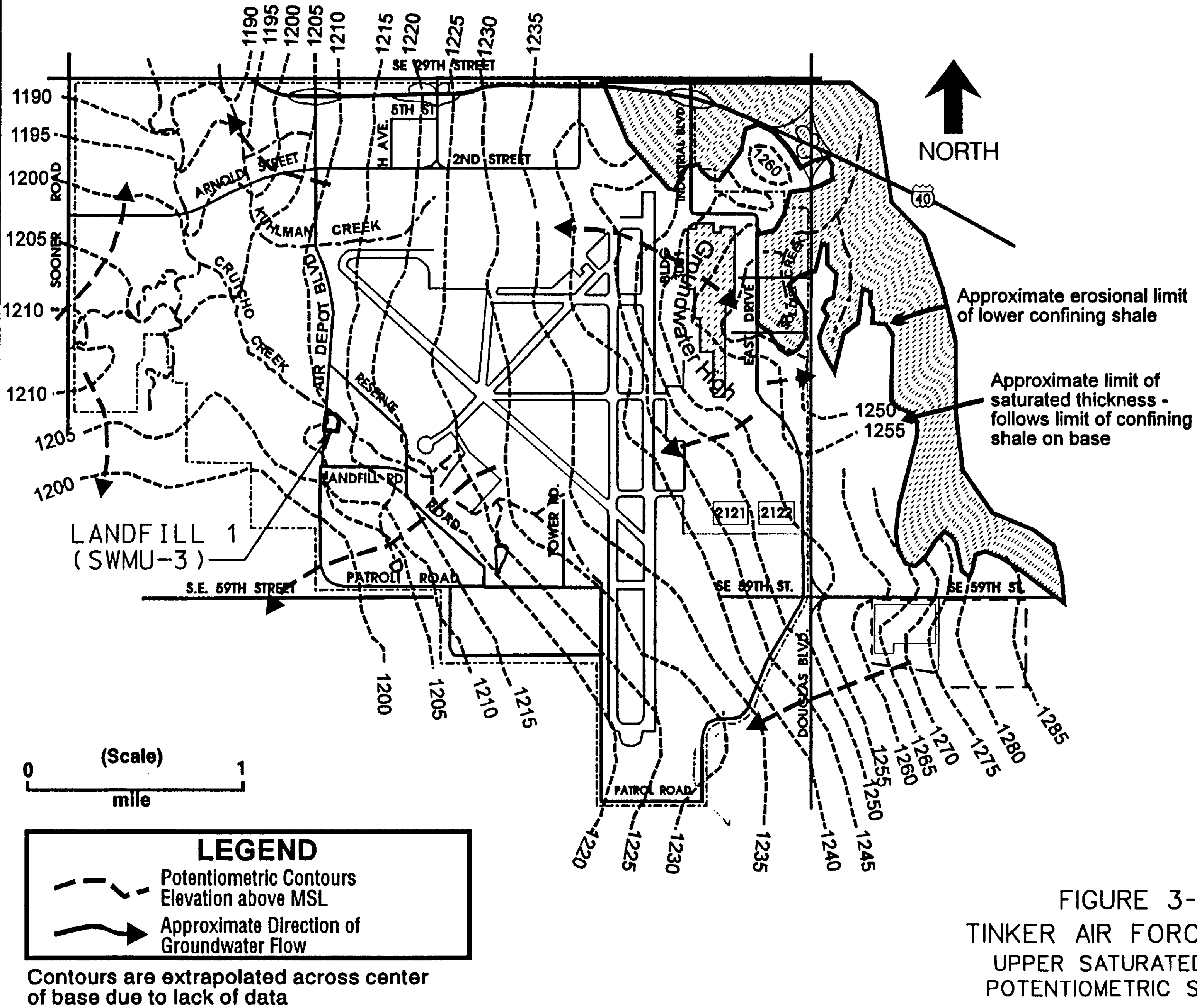

FIGURE 3-4
TINKER AIR FORCE BASE
UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 23MAR94	DATE LAST REV.:	DRAFT. CHCK. BY:	INITIATOR: C.WALLACE	DWG. NO.: 40983209C.
DRAWN BY: C.E.TUMLIN	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J.TAYLOR	PROJ. NO.: 409832

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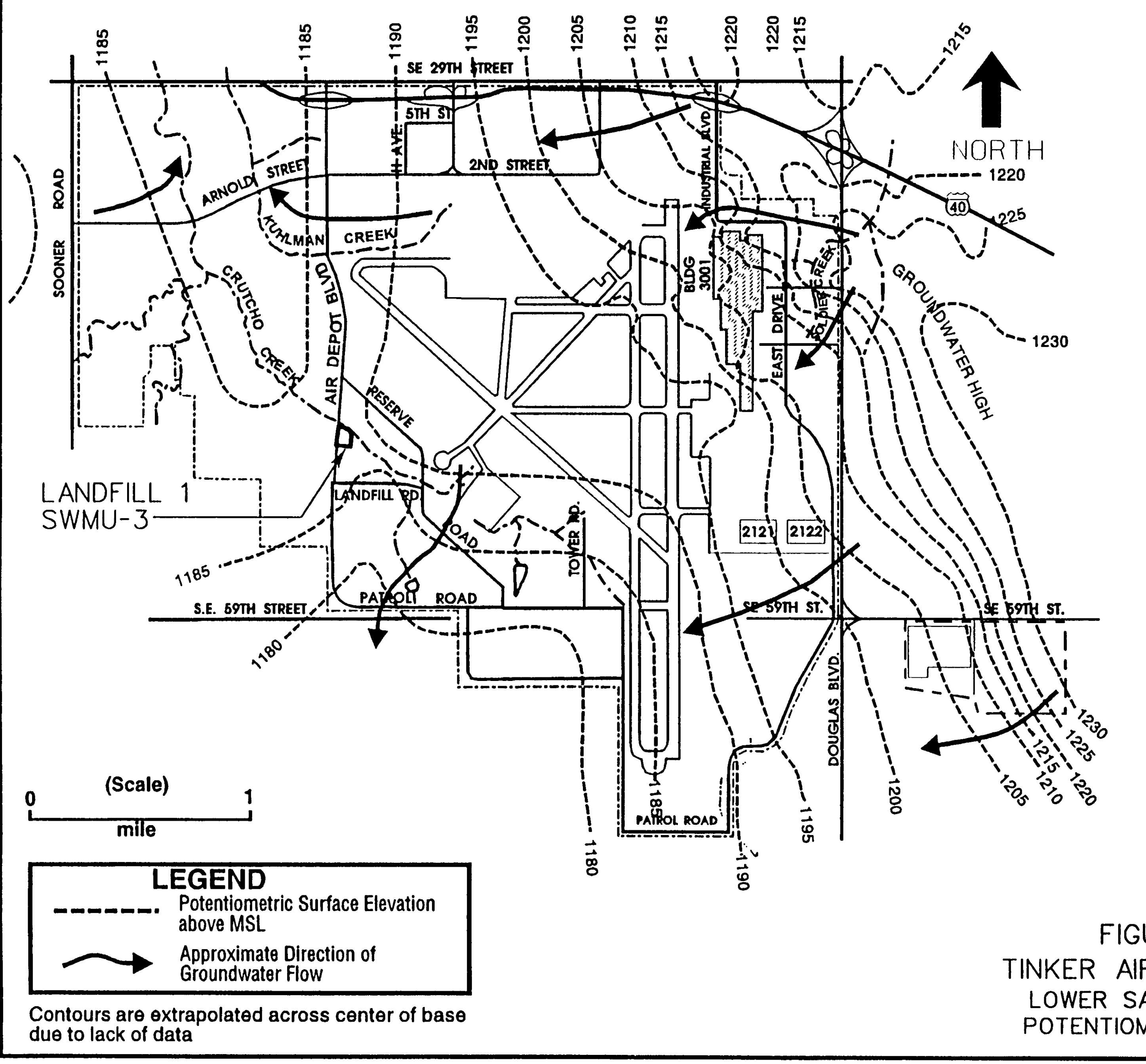

FIGURE 3-5
TINKER AIR FORCE BASE
LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 23MAR94	DATE LAST REV.:	DRAFT. CHCK. BY:	INITIATOR: C.WALLACE	DWG. NO.:409832O9C.
DRAWN BY: C.E.TUMLIN	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J.TAYLOR	PROJ. NO.:409832

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hydrogeologic data indicate that the vadose zone does not exist west of a north-south line located approximately 500 to 1,000 feet west of the main runway; consequently, the USZ is not perched west of this line. However, based on potentiometric head data from wells screened above and below the confining shale layer, the USZ remains a discrete aquifer zone distinct from the LSZ even over the western part of the Base. In areas where several shales interfinger to form the lower confining interval rather than a single shale bed, "gaps" may occur. In general, these "gaps" are not holes in the shale, but are places where multiple shales exist that are separated by slightly more permeable strata. Hydrologic data from monitoring wells indicate that these zones allow increased downward flow of groundwater above what normally leaks through the confining layer.

The LSZ is hydraulically interconnected and can be considered one aquifer zone down to approximately 200 feet. This area includes what was referred to by the USACE as the top of regional and regional zones. Hydrogeologic data from wells screened at different depths at the same location within this zone, however, provide evidence that locally a significant vertical (downward) component of groundwater flow exists in conjunction with lateral flow. The magnitude of the vertical component is highly variable over the Base. Preliminary evidence suggests that the LSZ is hydraulically discrete from the producing zone. Due to variations in topography, the top of the lower zone is found at depths ranging from 50 to 100 feet below ground surface under the eastern parts of the Base and as shallow as 30 feet to the west. Differences in potentiometric head values found at successive depths are due to a vertical (downward) component of groundwater flow in addition to lateral flow and the presence or absence of shale layers which locally confine the aquifer system. The LSZ extends east of the Base (east of Soldier Creek) beyond the limits of the USZ where it becomes the first groundwater zone encountered in off-Base wells. Because of the regional dip of bedding, groundwater gradient, and topography, the LSZ just east of the Base is generally encountered at depths less than 20 feet.

3.3.2 Site Hydrology

The groundwater beneath Landfill 1 exists in three distinct zones; the HWBZ, USZ, and LSZ. As stated in Section 3.3.1, the HWBZ is a perched water bearing zone developed in the southwest quadrant of Tinker AFB in the vicinity of Landfills 1 through 4. This zone is characterized by numerous thin saturated siltstone and sandstone beds alternating with shale beds. Delineation of this zone is complicated by a complex stratigraphy of discontinuous water bearing and sealing beds. Due to the complex stratigraphy and limited well control, the HWBZ and USZ are both considered as the USZ for the purposes of this report.

The uppermost saturated zone is the USZ. This zone, which by definition includes the HWBZ, is hydraulically connected to the water encountered in the landfill trenches and Crutcho Creek. Figure 3-4, which presents the potentiometric surface for the USZ in the Tinker AFB area, shows that groundwater flow in the vicinity of Landfill 1 is generally to the southwest.

The deepest hydrogeologic zone identified at the site is the LSZ. The LSZ is composed primarily of interbedded shale, siltstone, and sandstone. Figures presented in the RI report (USACE, 1993) depicting potentiometric surfaces for groundwater based on 1987 and 1990 monitoring well data show groundwater flowing in different directions. The 1987 contours show the LSZ flowing to the southeast in the area of Landfill 1; the 1990 contours show the LSZ groundwater flowing radially away from the northern portion of the landfill. However, the overall flow direction is to the south as shown in Figure 3-5. The LSZ formation was encountered at depths of 50 to 70 feet below grade and extended to a maximum depth of 125 feet before encountering a lower confining unit. The permeability of the formation was measured to be 1.2×10^{-3} centimeters per second (cm/s). The estimated flow rate of the LSZ is 48 feet per day.

The USZ and the LSZ are separated by a low permeability shale layer. This shale interval, which is part of the Hennessey Group, varies in thickness and pinches out north of Landfill Road underneath Landfill 1. The shale interval acts as the lower confining bed for the USZ and, therefore, perches the USZ. This shale interval is the second mappable layer discussed earlier under the section on stratigraphic correlation. The landfill trenches are set within and underlain by clay. The clay is a low-permeability layer, but it does not present as much of a barrier as the shale layer to the south. Average permeabilities for the clay and shale layers were reported to be 1.4×10^{-8} cm/s and 3×10^{-9} cm/s, respectively.

The USZ is a sandstone layer across the site. PVC pipes set in the landfill trenches have water levels corresponding to the USZ. The flow of the USZ moves toward Crutcho Creek from a local potentiometric high under Landfill 3 and southwest on the southern side of the high. The USZ sandstone was encountered at a depth between 15 and 30 feet below grade and ranged in thickness from a few feet to as much as 25 feet. The USZ is underlain by a substantial layer of shale and siltstone ranging in thickness from 8 to 25 feet. Vertical migration of the USZ groundwater and contaminants occurs primarily by movement through preferential pathways in the formation under semiconfined and confined conditions, with the interbedded coarser-grained material acting as a conduit to the LSZ. The permeability of the

USZ formation was measured to be 1.4×10^{-3} cm/s, and that of the underlying siltstone to be 3×10^{-8} cm/s. The estimated flow rate of the USZ is 113 feet per year.

3.4 Soils

Three major soil types have been mapped in the Tinker AFB area and are described in Table 3-2 (U.S. Department of Agriculture [USDA], 1969). The three soil types, the Darrell-Stephenville, Renfrow-Vernon-Bethany, and Dale-Canadian-Port, consist of sandy to fine sandy loam, silt loam, and clay loam, respectively. The Darrell-Stephenville and the Renfrow-Vernon-Bethany are primarily residual soils derived from the underlying shales of the Hennessey Group. The Dale-Canadian-Port association is predominantly a stream-deposited alluvial soil restricted to stream floodplains. The thickness of the soils ranges from 12 to 60 inches. Landfill 1 lies entirely within the Renfrow-Vernon-Bethany soil association.

Table 3-2

Tinker AFB Soil Associations
(Source: USDA, 1969)

Association	Description	Thickness (in.)	Unified Classification	Permeability (in./hr)
Darrell-Stephenville: loamy soils of wooded uplands	Sandy loam Sandy clay loam Soft sandstone (Garber Sandstone)	12-54	SM,ML,SC	2.0-6.30
Renfrow-Vernon-Bethany: loamy and clayey soils on prairie uplands	Silt loam - clay Clay loam Shale (Fairmont Shale)	12-60	ML,CL,MH,CH	<0.60-0.20
Dale-Canadian-Port: loamy soil on low benches near large streams	Fine sandy loam Silty clay loam Loam Clay loam	12-60	SM,ML,CL	0.05-6.30

4.0 Source Characterization

Landfill 1 was used primarily for the disposal of all solid and liquid general refuge generated at Tinker AFB during the period from 1942 through 1945. The landfill also received industrial waste solids and may have received waste solids from the domestic waste treatment plant (Radian, 1985a). Boring samples taken at the site revealed the presence of mixed trash in the landfill trenches. The burned trash remnants found were composed primarily of wood, metal, paper, rubber, and plastic materials. The estimated quantity of waste placed in Landfill 1 is approximately 21,780 yd^3. The landfill is located in the southwest corner of the Base.

During the course of the remedial investigations conducted by the USACE, two IRP soil borings (L1-1 and L1-2) were drilled within the landfill trenches. The borings were drilled with an auger to a depth of 34 and 17 feet, respectively, with samples of the waste in the trenches collected when encountered. The waste encountered was composited into one sample for analysis. Upon completion of each boring, the coordinates and ground elevations were surveyed for each boring. The landfill was found to cover approximately 1.5 acres. Geologic logs for the boring are contained in the USACE 1993 RI report. Table 4-1 contains the waste description and depth of occurrence for both borings (USACE, 1993). Waste materials were encountered in both trench borings.

The soil/waste samples were analyzed for volatile organic compounds (VOC), semivolatile organic compounds (SVOC), metals, cyanide, total organic carbon (TOC), pH, conductivity, and pesticides. VOCs, SVOCs, and metals were detected in the soil samples collected. A summary of the analytical results from the trench soil samples is provided and discussed in detail in Chapter 5.0.

Groundwater was encountered within the landfill trenches during the drilling of the soil borings. The trench water was sampled to determine the quality of the USZ groundwater beneath the landfill. Groundwater within the landfill trenches was found to be contaminated through contact with the waste material disposed of in the landfill. The nature and extent of soil and groundwater contamination is discussed in detail in Chapter 5.0, Contaminant Characterization.

Table 4-1

Landfill No. 1 Waste
SWMU-3, Landfill 1, Tinker AFB

Boring No.	Waste Description	Depth (feet)
L1-1	Greenish material, paper, scrap metal, wood, plastic	7.5-13.0
L1-2	Wood, paper, rubber hose, wire	8.0-16.0

Reference: U.S. Army Corps of Engineers (USACE), RI Report, Landfill No. 1, October 1993.

5.0 Contaminant Characterization

Through several phases of investigation, soil and groundwater samples have been collected in and around Landfills 1 through 4 to determine if any environmental contamination has occurred as a result of past waste disposal practices. The investigations have focused primarily on characterizing the materials disposed of within the landfills and on the nature and extent of contaminated soil and groundwater beneath and surrounding the landfills.

A determination of the nature and extent of contaminants migrating specifically from Landfill 1 is complicated by the close proximity of Landfills 2 through 4 to the southeast and the Fire Training Area 1 (FTA1) to the northwest. The determination of "upgradient" or "background" with respect to Landfill concentrations is complicated by multiple potential source areas and complex stratigraphy. Due to the limited number of sampling locations associated with Landfill 1, the contaminant characterization will consist of summarizing the data collected to date and comparing the concentrations of contaminants detected to specific action levels.

Soils. During RI activities performed by the USACE under the IRP (USACE, 1993), two samples were obtained from two soil borings (L1-1 and L1-2) drilled into the landfill. Both soil samples were collected in February 1987 and were analyzed for the same array of chemical constituents. The following analytes were among the parameters tested: VOCs, SVOCs, metals, pesticides, polychlorinated biphenyl (PCB), cyanide, TOC, pH, and conductivity.

Groundwater. Groundwater in the vicinity of Landfill 1 was investigated by collecting samples from soil borings within the landfill and from monitoring wells around the landfill. The groundwater samples from the borings were submitted for analysis of the following parameters: VOCs, SVOCs, metals, pesticides, PCBs, cyanide, TOC, oil and grease, chloride, sulfate, pH, conductivity, and radiometrics.

Six groundwater monitoring wells are in close proximity to the landfill as shown in Figure 2-1. Monitoring wells MW-1B, 2A, and 9A are screened across the USZ. Monitoring wells MW-2B and 9B are screened across the LSZ. Monitoring well MW-1A is screened across multiple zones (USZ and top LSZ) and the data from the well was not included. Groundwater samples from monitoring wells were submitted for analysis of the same parameters as the water samples collected from the soil borings.

5.1 Constituents of Potential Concern

The analytical results of soil and groundwater samples from Landfill 1 are available from past IRP investigation activities. Evaluation of these analytical results for the purpose of identifying constituents of potential concern with respect to both human health and the ecological impacts has not been performed. However, an interpretation has been made by comparing analytical results to specific action levels. The action levels for comparison are maximum contaminant levels (MCL), SWMU corrective action levels (CAL), and water quality standards (WQS). The basis for establishing action levels and their definitions is discussed in Section 7.0. In addition, the analytical results from soil samples for metals have been compared to elemental background concentrations in soils.

For soils data, metals concentrations will be compared to established background concentrations. Those metals detected at levels within the range of background concentrations will be considered as naturally occurring and, therefore, below action levels. Any metals at detected concentrations above background, or for which no background concentration has been established, will be compared to SWMU CALs. All other analytes detected will also be compared to SWMU CALs. For groundwater data, all analytes detected will be compared to MCLs. For those analytes for which no MCL has been established, the analytes will be compared to SWMU CALs; if no SWMU CALs have been established, WQSs will be used for comparison.

5.2 Soil Characterization

During the RI, the USACE assessed the magnitude and extent of contamination originating from historical landfill disposal practices. Two soil borings (L1-1 and L1-2) were advanced into areas of suspected contamination at Landfill 1 in 1987. The results of the soil investigations are discussed with respect to the analytes detected and background metals concentrations in the following sections.

Establishment of Surficial Soil Background Concentrations. Background soil concentrations for trace metals were determined based on a study performed by the USGS (1991). The study area was confined to approximately four counties in central Oklahoma bounded by 34° 45' and 36° north latitude and 96° 45' and 97° 45' west longitude. Tinker AFB lies at the approximate center of this area. A total of 293 B-horizon soil samples were collected within this area. Soil samples were collected at the top of the B-horizon, which was usually 20 to 30 centimeters below the surface but ranged from 3 centimeters to 50 centime-

Table 5-1

Background Concentrations of Trace Metals in Surface Soils[a] SWMU-3, Landfill 1, Tinker AFB

(Page 1 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Concentration in %			
Aluminum	0.005	0.38	8.9
Cadmium	0.005	0.01	9.4
Iron	0.005	0.18	5.8
Magnesium	0.005	0.02	5.3
Phosphorous	0.005	0.06	0.019
Potassium	0.05	0.1	2.4
Sodium	0.005	0.02	0.99
Titanium	0.005	0.04	0.42
Concentrations in ppm			
Arsenic	0.1	0.6	21
Barium	1	47	6400
Beryllium	1	<1	3
Bismuth	10	<DL[b]	<DL
Cadmium	2	<DL	<DL
Cerium	4	14	110
Chromium	1	5	110
Cobalt	1	<1	27
Copper	1	<1	59
Europium	2	---[c]	---
Gallium	4	<4	23
Gold	8	<DL	<DL
Holmium	4	<DL	<DL
Lanthanum	2	7	51
Lead	4	<4	27
Lithium	2	5	100

Table 5-1

(Page 2 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Manganese	10	24	3400
Molybdenum	2	<DL	<DL
Neodymium	4	6	47
Nickel	2	<2	61
Niobium	4	<4	16
Scandium	2	<2	15
Selenium	0.1	<0.1	1.2
Silver	2	<DL	<DL
Strontium	2	13	300
Tantalum	40	<DL	<DL
Thorium	1	<1.40	15.00
Tin	10	<DL	<DL
Uranium	0.1	0.650	6.400
Vanadium	2	5	220
Ytterbium	1	<1	3
Yttrium	2	3	43
Zinc	2	3	79

[a]All B-horizon soil samples (293) from USGS, 1991.
[b]All concentrations below the lower limits of determination.
[c]Insufficient or no data.

The surficial soil concentrations for trace metals reported by the USGS were used to establish the background ("background") concentration for trace metals at all Tinker AFB study sites. Measured environmental concentrations of trace metals in surficial soils at study sites are represented by the arithmetic upper 95th confidence interval on the mean of a normal distribution. The intent of this approach is to estimate a Reasonable Maximum Exposure case (i.e., well above the average case) that is still within a range possible exposures. If the environmental concentration for a given analyte is below or within the minimum-maximum range of background concentrations, that analyte was considered to be naturally occurring and no further concern to this investigation. In an analyte's environmental concentration exceeded background, it was identified as requiring further study.

Establishment of surficial soil background concentrations using the top of the B-horizon is a conservative approach in that it is unlikely to reflect all possible anthropogenic influences. Trace metal inputs from anthropogenic sources other than those related to study site-specific disposal activities or operations will not necessarily to be eliminated using this approach. Therefore, responsibility may be taken for more trace metal impacts than are actually attributable to a given site.

Landfill Trenches. Borings L1-1 and L1-2 were drilled into the former landfill trenches and samples collected for laboratory analysis. Table 5-2 is a summary of those analytes, which were detected above the analytical method detection limit. Nine metals were detected in the samples. All metals except cadmium and mercury were detected at concentrations within the established background levels as presented in Table 5-1. Cadmium was detected at a maximum concentration of 2.0 milligrams per kilogram (mg/kg), which is the detection limit for the background data set for this metal. Mercury was detected at a maximum concentration of 0.27 mg/kg. Background data for mercury was not available. Both cadmium and mercury were detected at concentrations below their respective action levels.

Three organic compounds were detected. Methylene chloride, acetone, and di-n-butyl phthalate were detected at maximum concentrations of 18, 1400, and 1600 micrograms per kilogram (μg/kg), respectively. No organic compounds were detected at concentrations above action levels.

No pesticides or PCBs were detected in either boring.

Table 5-2

Summary of Analytical Results, Trench Soil Samples, 1987 Soil Sampling SWMU-3, Landfill 1, Tinker AFB

	Action Level[a]	L1-1	L1-2
Volatiles (µg/kg)			
Methylene chloride	90,000	23J	18
Acetone	8,000,000	1400	1200
Semivolatiles (µg/kg)			
Di-n-butyl phthalate	8,000,000	<420	1600
Metals (mg/kg)			
Arsenic	80	2.6	1.1
Barium	4,000	620	340
Cadmium	40	2.0	1.4
Chromium		8.6	15
Lead		26	13
Mercury	20	0.27	0.23
Nickel	2,000	13	11
Silver	200	0.67	<0.5
Zinc		40	41
Indicators			
TOC (mg/kg)		12,000	3600
pH		7.25	7.21
Conductivity (µmhos/cm)		830	880

J = Associated numerical value is an estimated quantity.
Note: Laboratory results obtained from Appendix Q of the RI Report (USACE, 1993).
[a]SWMU corrective action levels (CAL) as specified in Section 7.0.

5.3 Groundwater Characterization

5.3.1 Landfill Trenches

Groundwater samples were collected from soil borings L1-1 and L1-2 and submitted for laboratory analysis. Table 5-3 is a summary of those analytes that were detected above the analytical method detection limit. Three VOCs were detected in the water samples. Methylene chloride, acetone, and chlorobenzene were detected at maximum concentrations of 370, 13, and 6 µg/L, respectively. Methylene chloride was the only VOC detected at a concentration above its action level. Two SVOCs were detected in the samples. Diethyl phthalate was detected at maximum concentration of 170 µg/L and 4-methylphenol was detected at 100 µg/L. Neither compound was detected at a concentration exceeding its action level.

Twelve metals were detected in the groundwater samples as shown in Table 5-3. Metals detected above MCLs included barium, cadmium, chromium, lead, and nickel. Barium, cadmium, chromium, lead, mercury, and nickel were all detected at concentrations above their respective action limits.

Indicator parameters detected included TOC, oil and grease, chloride, and sulfate at maximum concentration of 120, 3.2, 140, and 110 milligrams per liter (mg/L), respectively. The maximum pH of the trench water was 6.89.

Three radiometric measurements were performed on the trench water samples. Gross alpha, gross beta, and total radium readings measured maximum activity of 26, 66, and 10 pico-curies per liter (pCi/L), respectively. Gross alpha readings were measured at levels exceeding the action limit for gross alpha activity.

5.3.2 Upper Saturated Zoned

Groundwater samples were collected periodically from monitoring wells MW-1B, 2A, and 9A, which are completed within the USZ. Table 5-4 is a summary of those analytes detected above the analytical method detection limit from samples collected between 1987 and 1992. Sixteen VOCs were detected in the groundwater samples. Of the 16 VOCs, methylene chloride, trichloroethene, benzene, and vinyl chloride were detected at levels exceeding their respective action levels. Six SVOCs were detected in the groundwater samples. Bis(2-ethylhexyl)phthalate was the only SVOC detected above its action level.

Table 5-3

Summary of Analytical Results, Trench Water, 1987 Water Sampling SWMU-3, Landfill 1, Tinker AFB

(Page 1 of 2)

	Action Levels[a]	L1-1	L1-2
Volatiles (μg/L)			
Methylene chloride	5[a]	<5	370
Acetone	4,000[b]	13	<500
Chlorobenzene	100[a]	6	<250
Semivolatiles (μg/L)			
4-Methylphenol		<20	100
Diethyl phthalate	30,000[b]	170	65
Metals (μg/L)			
Arsenic	50[a]	10	7.9
Barium	2000[a]	4,500	9,500
Cadmium	5[a]	120	210
Chromium	100[a]	190	650
Iron		91,000	260,000
Lead	15[a]	830	1,200
Manganese		4,500	5,800
Mercury	2[a]	0.96	10
Nickel	100[a]	150	270
Selenium	50[a]	<0.4	0.70
Silver	64,620[c]	58	30
Zinc		2,800	11,000

Table 5-3

(Page 2 of 2)

	Action Levels[a]	L1-1	L1-2
Indicators			
TOC (mg/L)		37	120
Oil and grease (mg/L)		3	3.2
Chloride (mg/L)		73	140
Sulfate (mg/L)		20	110
pH		6.89	6.32
Conductivity (μmhos/cm)		2180	2010
Radiometrics (pCi/L)			
Gross alpha	15	26	24
Counting error		22	19
Gross beta		66	44
Counting error		14	13
Total radium		10	7
Counting error		3	3

[a]Maximum contaminant levels (MCLs) as specified in Section 7.0.
[b]SWMU contaminant action levels (CALs) as specified in Section 7.0.
[c]Water quality standards (WQSs) as specified in Section 7.0.

Note: Laboratory results obtained from Appendix P of the RI Report (USACE, 1993) unless noted otherwise.

Table 5-4

Summary of 1986, 1987, 1988, 1989, 1990, and 1992 Analytical Results
Upper Saturated Zone Monitoring Wells
SWMU-3, Landfill 1, Tinker AFB

(Page 1 of 8)

	Action Levels[a]	MW-1B					MW-2A				
		1987[b]	1988	1989	1990	1992	1986[b]	1988	1989	1990	1992
Volatiles (µg/L)											
Methylene chloride	5	2J	<5	<5	<10	<0.6	<5	<5	<5	<10	16B
1,2-Dichloroethene (total)		NA	<5	<5	NRT	NRT	NA	8	11	NRT	NRT
Trichloroethene	5	<5	<5	<5	<5	16	<5	0.6J	<5	<5	2
1,1-Dichloroethene	7	NA	<5	<5	<5	2	NA	<5	<5	<5	<0.5
Benzene	5	NA	<5	<5	<5	70	NA	<5	<5	<5	0.6
Chlorobenzene	100	<5	<5	<5	<5	1	<5	<5	<5	<5	7
Ethyl benzene	700	NA	<5	<5	<5	3	NA	<5	<5	<5	<0.5
Isopropylbenzene		NA	NRT	NRT	NRT	0.8	NA	NRT	NRT	NRT	<0.5
Tetrachloroethene	5	NA	<5	<5	<5	3	NA	<5	<5	<5	<0.5
Toluene	1000	<5	<5	<5	<5	1	<5	1J	<5	<5	0.8
Xylenes (total)	10,000	NA	<5	<5	<5	1	NA	<5	<5	<5	NRT
Cis-1,2-dichloroethene	70	NA	NRT	NRT	NRT	11	NA	NRT	NRT	NRT	8
m-Xylene		NA	NRT	NRT	NRT	0.5	NA	NRT	NRT	NRT	<0.5

Table 5-4

(Page 2 of 8)

	Action Levels[a]	MW-1B					MW-2A				
		1987[b]	1988	1989	1990	1992	1986[b]	1988	1989	1990	1992
Volatiles (Continued)											
p-Xylene		NA	NRT	NRT	NRT	0.5	NA	NRT	NRT	NRT	<0.5
Vinyl chloride	2	<10	<10	<10	<10	<0.5	<10	<10	<10	<10	5
Trans-1,2-dichloroethene	100	<5	<5[c]	<5[c]	<5	<0.5	12	8[c]	11[c]	<5	0.6
Semivolatiles (μg/L)											
Bis(2-ethylhexyl)phthalate	6	70	<10	<10	35	<11	75	<10	14	41	2J
Di-n-octyl phthalate		<50	<10	<10	16	<11	<10	<10	22	17	<18
Dimethyl phthalate		NA	<10	<10	<10	25	NA	<10	<10	<10	380
1,2-Dichlorobenzene	600	NA	<10	<10	<10	<0.5	NA	<10	<10	<10	1
1,4-Dichlorobenzene	75	<50	<10	<10	<10	<11	<10	<10	<10	<10	0.6
Naphthalene		NA	<10	<10	<10	<0.5	NA	<10	<10	<10	3B
Metals (μg/L)											
Arsenic	50	1.1	<1	<1	1.5	5.9	17	46	21	10.5	15
Barium	2000	3800	2800	3100	194	1840	2700	2800	3200	168	2860
Cadmium	5	<7.5	<5	<5	<10	<5	10	<5	<5	<10	<5
Chromium	100	50	<5	9	<10	<7	<10	<5	5	<10	<7
Iron		34000	NRT	85	239	NRT	NRT	NRT	1000	92.1	NRT

Table 5-4

(Page 3 of 8)

	Action Levels[a]	MW-1B					MW-2A				
		1987[b]	1988	1989	1990	1992	1986[b]	1988	1989	1990	1992
Metals (µg/L) (Continued)											
Lead	15	70	13	15	<20	<42	53	21	22	<20	<42
Manganese		2600	NRT	4600	735	NRT	NRT	NRT	610	54.8	NRT
Mercury	2	0.26	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	0.12	<0.2	<0.2
Nickel	100	60	NRT	NRT	NRT	<15	240	NRT	NRT	NRT	15.8
Selenium	50	0.5	<0.4	<0.4	1.0	<2	<0.4	<0.4	<0.4	<1.0	<2
Silver	64,620[d]	<10	<5	<5	<10	<7	13	<5	<5	<10	<7
Zinc		120	NRT	NRT	NRT	NRT	190	NRT	NRT	NRT	NRT
Indicators											
pH		7.05	7.12	6.72	6.78	NRT	7.33	7.38	7.25	7.02	NRT
Chloride (mg/L)		49	57	33	32.5	NRT	137.5	220	210	178	NRT
Sulfate (mg/L)		149	9	<2	5.87	NRT	3	6.4	1.2	<2.0	NRT
Oil and grease (mg/L)		<1	NRT	<1	<5	NRT	<1	NRT	<1	<5	NRT
TOC (mg/L)		5.7	3.9	7	1.19	1.7	7.5	5.2	9.51	1.37	10.6
Conductivity (µmhos/cm)		1588	1490	1060	1460	NRT	1729	1760	1240	1721	NRT
Radiometrics (pCi/L)											
Gross alpha	15	16	NRT	16.1	4	NRT	<2	NRT	3.86	3	NRT
Counting error		7	NRT	20.9	3	NRT	--	NRT	1.24	2	NRT

Table 5-4

(Page 4 of 8)

	Action Levels[a]	MW-1B					MW-2A				
		1987[b]	1988	1989	1990	1992	1986[b]	1988	1989	1990	1992
Gross beta		8	NRT	38.7	9	NRT	<3	NRT	2.35	7	NRT
Radiometrics (pCi/L) (Continued)											
Counting error		6	NRT	16.2	5	NRT	--	NRT	9.12	3	NRT
Ra-226 + Ra-228	20	NA	NRT	0.37	NRT	NRT	NRT	NRT	0.45	NRT	NRT
Counting error		NA	NRT	0.18	NRT	NRT	NRT	NRT	0.19	NRT	NRT
Total radium		14	NRT	NRT	2	NRT	NRT	NRT	NRT	2	NRT
Counting error		7	NRT	NRT	1	NRT	NRT	NRT	NRT	1	NRT

Table 5-4

(Page 5 of 8)

	Action Levels[a]	MW-9A					
		1986[b]	1988	1988	1989	1990	1992
Volatiles (µg/L)							
Methylene chloride	5	<5	<8	<8	<5	2J	<0.6
1,2-Dichloroethene (total)		NA	<8	<8	<5	<5	NRT
Trichloroethene	5	<5	<8	<8	<5	<5	1
1,1-Dichloroethene	7	NA	<8	<8	<5	<5	<0.5
Benzene	5	NA	<8	<8	<5	<5	<0.5
Chlorobenzene	100	<5	<8	<8	<5	<5	<0.5
Ethyl benzene	700	NA	<8	<8	<5	<5	<0.5
Isopropylbenzene		NA	NRT	NRT	NRT	NRT	<0.5
Tetrachloroethene	5	NA	<8	<8	<5	<5	<0.5
Toluene	1000	<5	<8	<8	<5	<5	<0.5
Xylenes (total)	10,000	NA	<8	<8	<5	<5	NRT
Cis-1,2-dichloroethene	70	NA	NRT	NRT	NRT	NRT	0.5
m-Xylene		NA	NRT	NRT	NRT	NRT	<0.5
p-Xylene		NA	NRT	NRT	NRT	NRT	<0.5
Vinyl chloride	2	<10	<17	<17	<10	<10	<0.5
Trans-1,2-dichloroethene	100	<5	<8[c]	<8[c]	<5[c]	<5[c]	<0.5

Table 5-4

(Page 6 of 8)

	Action Levels[a]	MW-9A					
		1986[b]	1988	1988	1989	1990	1992
Semivolatiles (μg/L)							
Bis(2-ethylhexyl)phthalate	6	10J	<10	<10	<10	6BJ	<10
Di-n-octyl phthalate		<10	<10	<10	<10	<10	<10
Dimethyl phthalate		NA	<10	<10	<10	<10	<10
1,2-Dichlorobenzene	600	NA	<10	<10	<10	<10	<0.5
1,4-Dichlorobenzene	75	<10	<10	<10	<10	<10	<10
Naphthalene		NA	<10	<10	<10	<10	1B
Metals (μg/L)							
Arsenic	50	2	2	2	2	1.4	<2
Barium	2000	800	580	650	790	72.2	471
Cadmium	5	10	<5	<5	<5	<10	<5
Chromium	100	<10	11	<5	170	<10	<7
Iron		NRT	NRT	NRT	100	<10	NRT
Lead	15	80	12	13	20	<20	<42
Manganese		NRT	NRT	NRT	400	31.5	NRT
Mercury	2	0.22	0.1	<0.1	<0.1	<0.2	<0.2
Nickel	100	140	NRT	NRT	NRT	NRT	<15
Selenium	50	<0.4	2	0.50	<0.4	<1	<2

Table 5-4

(Page 7 of 8)

	Action Levels[a]	MW-9A					
		1986[b]	1988	1988	1989	1990	1992
Metals (μg/L) (Continued)							
Silver	64,620[d]	<10	<5	<5	<5	<10	<7
Zinc		45	NRT	NRT	NRT	NRT	NRT
Indicators							
pH		7.09	7.54	7.22	7.13	7.15	NRT
Chloride (mg/L)		125	84	72	98	54.4	NRT
Sulfate (mg/L)		8	14	14	5	17.4	NRT
Oil and grease (mg/L)		1.8	NRT	NRT	<1	<5	NRT
TOC (mg/L)		4	13	14	5.3	1.22	1.4
Conductivity (μmhos/cm)		1500	1250	1217	880	1066	NRT
Radiometrics (pCi/L)							
Gross alpha	15	<2	NRT	NRT	6	<2	NRT
Counting error		--	NRT	NRT	11	--	NRT
Gross beta		<3	NRT	NRT	12	4	NRT
Counting error		--	NRT	NRT	9.7	3	NRT
Ra-226 + Ra-228		NRT	NRT	NRT	0.3	NRT	NRT

Table 5-4

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	Action Levels[a]	MW-9A					
		1986[b]	1988	1988	1989	1990	1992
Radiometrics (pCi/L) (Continued)							
Counting error		NRT	NRT	NRT	0.2	NRT	NRT
Total radium	20	NRT	NRT	NRT	NRT	2	NRT
Counting error		NRT	NRT	NRT	NRT	1	NRT

[a]Maximum contaminant levels (MCL), as specified in Section 7.0.
[b]Analytical data not available; therefore, not able to confirm. Data obtained from the RI Report (USACE, 1993).
[c]Result for 1,2-dichloroethene (total) presented in analytical summary in lieu of trans-1,2-dichloroethene. Result for trans-1,2-dichlorethene obtained from the RI Report (USACE, 1993).
[d]Water quality standards (WQS) as specified in Section 7.0.
J = Associated numerical value is an estimated quantity.
B = Compound also found in blank.
NRT = Not reported and/or tested.
NA = Not Available.
NOTE: Laboratory results obtained from Appendix O of the RI Report (USACE, 1993) unless noted otherwise.

Twelve metals were detected in the groundwater samples as shown in Table 5-4. Metals detected above their respective action levels included barium, cadmium, chromium, lead, and nickel.

Indicator parameters detected included chloride, sulfate, oil and grease, and TOC at maximum concentrations of 220, 149, 1.8, and 14 mg/L, respectively. Measurements of pH ranged from 6.72 to 7.54. Measurements of conductivity ranged from 880 to 1760 µmhos/cm.

Four radiometric measurements were performed on groundwater samples. Gross alpha, gross beta, radium (Ra)-226 and Ra-228, and total radium readings measured maximum activity of 16.1, 38.7, 0.45, and 14 pCi/L, respectively. The maximum measured gross alpha activity of 16.1 pCi/L is just above the action level of 15 pCi/L.

5.3.3 Lower Saturated Zone

Groundwater samples were collected periodically from monitoring wells MW-2B and MW-9B, which are completed in the LSZ. Table 5-5 is a summary of those analytes detected above the analytical method detection limit from samples collected between 1988 and 1990. Two VOCs were detected in the groundwater samples. Both 1,2-dichloroethene and trichloroethene were detected above their action levels at maximum concentrations of 31 and 6 µg/L, respectively. Two SVOCs were detected in groundwater samples. Bis(2-ethylhexyl)phthalate was detected above the its action level at a maximum concentration of 21 µg/L. Di-n-octylphthalate was detected at a maximum concentration of 16 µg/L.

Seven metals were detected in groundwater samples as shown in Table 5-5. Lead was the only metal detected at concentrations above its action level.

Indicator parameters detected included chloride, sulfate, and TOC at maximum concentrations of 110, 8, and 42 mg/L, respectively. Measurements of pH ranged from 6.7 to 8.65. Measurements of conductivity ranged from 290 to 1,042 micromhos per centimeter (µmhos/cm).

Four radiometric measurements were performed on groundwater samples. Gross alpha, gross beta, Ra-226 and Ra-228, and total radium readings measured maximum activity of 38, 68, 0.89, and 5 pCi/L, respectively. The maximum gross alpha activity measured exceeded the action level of 15 pCi/L.

Table 5-5

Summary of 1986, 1988, 1989, 1990, and 1992 Analytical Results, Lower Saturated Zone Monitoring Wells SWMU-3, Landfill 1, Tinker AFB

(Page 1 of 4)

	Action Levels [a]	MW-2B		
		1988	1989	1990
Volatiles (μg/L)				
1,2-Dichloroethene (total)	5	<5	<5	NRT
Trichloroethene	5	<5	<5	<5
Methylene chloride	5	<5	<5	<10
Semivolatiles (μg/L)				
Bis(2-ethylhexyl)phthalate	6	<10	<10	39
Di-n-octyl phthalate		<10	<10	16
Metals (μg/L)				
Arsenic	50	1	<1	2.2
Barium	2000	840	940	41.6
Chromium	100	<5	7	<10
Iron		NRT	650	715
Lead	15	<10	17	<20
Manganese		NRT	91	26
Mercury	2	<0.1	0.1	<0.2
Indicators				
pH		7.5	8.65	6.7
Chloride (mg/L)		18	18	14.2
Sulfate (mg/L)		6	3	<2
TOC (mg/L)		1.7	4.2	<0.5
Conductivity (μmhos/cm)		735	290	620

Table 5-5

(Page 2 of 4)

	Action Levels [a]	MW-2B		
		1988	1989	1990
Radiometrics (pCi/L)				
Gross alpha	15	NRT	9.3	6
Counting error		NRT	6.4	4
Gross beta		NRT	22.9	10
Counting error		NRT	5.7	6
Ra-226 + Ra-228	20	NRT	0.89	NRT
Counting error		NRT	0.24	NRT
Total radium		NRT	NRT	2
Counting error		NRT	NRT	1

Table 5-5

(Page 3 of 4)

	Action Levels[a]	MW-9B 1988	MW-9B 1989	MW-9B 1990
Volatiles (µg/L)				
1,2-Dichloroethene (total)	5	31	24	NRT
Trichloroethene	5	6	<5	<5
Semivolatiles (µg/L)				
Bis(2-ethylhexyl)phthalate	6	<10	<10	21
Di-n-octyl phthalate		<10	<10	<10
Metals (µg/L)				
Arsenic	50	2	2	3.1
Barium	2000	720	1000	65
Chromium	100	<5	7	<10
Iron		NRT	500	578
Lead	15	<10	24	<20
Manganese		NRT	300	20.6
Mercury	2	<0.1	0.2	<0.2
Indicators				
pH		7.43	7.16	7.03
Chloride (mg/L)		110	90	59.1
Sulfate (mg/L)		8	2	6.05
TOC (mg/L)		1.7	3.7	<0.5
Conductivity (µmhos/cm)		1042	800	895
Radiometrics (pCi/L)				
Gross alpha	15	NRT	38	7
Counting error		NRT	20	4
Gross beta		NRT	68	15
Counting error		NRT	18	6
Ra-226 + Ra-228	20	NRT	0.6	NRT

Table 5-5

(Page 4 of 4)

	Action Levels[a]	MW-9B		
		1988	1989	1990
Radiometrics (pCi/L) (Continued)				
Counting error		NRT	0.2	NRT
Total radium		NRT	NRT	5
Counting error		NRT	NRT	2

[a]Maximum contaminant levels (MCLs) specified in Section 7.0.
NRT = Not reported and/or tested.

Note: Laboratory results obtained from Appendix O of the RI Report (USACE, 1993) unless noted otherwise.

5.4 Characterization Summary

Characterization of soil and groundwater with respect to the nature and extent of contaminants migrating specifically from Landfill 1 cannot be performed at this time due to the limited data available. Soil and water samples were only collected from two borings within the landfill. Also, additional well control is required to establish upgradient versus downgradient groundwater concentrations within both the USZ and LSZ.

Based on the existing data, a preliminary comparison was made of the analytes tested in the soil borings versus the USZ and LSZ wells. Table 5-6 shows a comparison of the maximum analytes detected in soil and groundwater for those analytes tested for each category. The comparison shows that of the 18 VOCs detected, only 3 were detected within the landfill soils or groundwater. In comparison, 17 of the VOCs were detected in the USZ, suggesting a possible source outside Landfill 1. Three SVOCs were detected within the soil or groundwater within the landfill, but these compounds were not found in the USZ wells around the landfill perimeter. Six SVOCs were detected in the USZ wells, but were not detected within the landfill, again suggesting an outside source.

Both cadmium and mercury were detected within the landfill soil at levels above background. Both metals were also detected in boring groundwater samples and USZ wells. Indicator parameters including TOC, oil and grease, chloride, and sulfate were detected in groundwater within and around the landfill.

Radiometric measurements for gross alpha, gross beta, and total radium were detected in groundwater within the landfill, as well as in USZ and LSZ perimeter wells. This data suggests that radioactive materials may potentially be leaching from the landfill.

These observations are preliminary only. Additional data and sampling locations will be required to characterize the full nature and extent of contamination within and migrating from Landfill 1.

Table 5-6

Comparison of Maximum Analytes Detected In Trench Soil and Water Samples versus USZ and LSZ Groundwater Samples SWMU-3, Landfill 1, Tinker AFB

(Page 1 of 2)

Analyte	Trench Soils	Trench Water	USZ Groundwater	LSZ Groundwater
Volatiles	(µg/kg)	(µg/L)	(µg/L)	(µg/L)
Methylene chloride	18	370	16B	ND
Acetone	1400	13	ND	ND
Chlorobenzene	ND	6	7	ND
1,2-Dichloroethene (total)	ND	ND	11	31
Trichloroethene	ND	ND	16	6
1,1-Dichloroethene	ND	ND	2	ND
Benzene	ND	ND	70	ND
Chlorobenzene	ND	ND	7	ND
Ethyl benzene	ND	ND	3	ND
Isopropylbenzene	ND	ND	0.8	ND
Tetrachloroethene	ND	ND	3	ND
Toluene	ND	ND	1	ND
Xylenes (total)	ND	ND	1	ND
Cis-1,2-dichloroethene	ND	ND	11	ND
m-Xylene	ND	ND	0.5	ND
p-Xylene	ND	ND	0.5	ND
Vinyl chloride	ND	ND	5	ND
Trans-1,2-dichloroethene	ND	ND	11	ND
Semivolatiles	(µg/kg)	(µg/L)	(µg/L)	(µg/L)
Di-n-butyl phthalate	1600	ND	ND	ND
4-Methylphenol	ND	100	ND	ND
Diethyl phthalate	ND	170	ND	ND
Bis(2-ethylhexyl)phthalate	ND	ND	75	39

Table 5-6

(Page 2 of 2)

Analyte	Trench Soils	Trench Water	USZ Groundwater	LSZ Groundwater
Semivolatiles (Continued)	(µg/kg)	(µg/L)	(µg/L)	(µg/L)
Di-n-octyl phthalate	ND	ND	17	16
Dimethyl phthalate	ND	ND	380	ND
1,2-Dichlorobenzene	ND	ND	1	ND
1,4-Dichlorobenzene	ND	ND	0.6	ND
Naphthalene	ND	ND	3B	ND
Metals	mg/kg	(µg/L)	(µg/L)	(µg/L)
Arsenic	2.6	10	46	3.1
Barium	620	9,500	3,800	1,000
Cadmium	2.0	210	10	ND
Chromium	8.6	650	170	7
Lead	26	1,200	80	24
Mercury	0.27	10	0.26	0.2
Nickel	13	270	240	ND
Selenium	ND	0.70	1.54	ND
Silver	0.67	58	13	ND
Zinc	41	11,000	190	ND
Indicators	mg/L	mg/L	mg/L	mg/L
TOC	12,000	120	14	17
Oil and grease	ND	3.2	1.8	ND
Chloride	ND	140	220	110
Sulfate	ND	110	149	8
Radiometrics	pCi/L	pCi/L	pCi/L	pCi/L
Gross alpha	NS	26	16	38
Gross beta	NS	66	39	68
Total radium	NS	10	2	5

B = Analyte detected in sample blanks.
ND = Not detected at the analytical method detection limit.
NS = Not samples.

6.0 Potential Receptors

A preliminary draft baseline risk assessment report (USACE, 1991) for Landfills 1 through 4 was issued by USACE in February 1991. The purpose of the risk assessment was to quantify the potential health risks to human receptors at the four sites. The risk assessment was prepared in accordance with EPA guidance documents current at the time. An assessment of site risks to ecological receptors was not included in the report.

The risk assessment treated Landfills 1 through 4 as one site. Therefore, the risks associated with Landfill 1 alone cannot be abstracted from the report. The following is a discussion of the potential receptors identified by the preliminary draft baseline risk assessment report.

6.1 Exposure Assessment Results/Human Receptors

An exposure assessment was performed to determine the potential human receptors and to analyze the potential exposure pathways at Landfills 1 through 4. Potentially exposed human populations were limited to industrial workers associated with Base operations for the following reasons:

- No completed exposure pathway exists now or in the foreseeable future which would potentially expose individuals outside the boundaries of Tinker AFB.
- Access to Tinker AFB is restricted to military personnel, civilian employees, and individuals such as retirees who are authorized to use Base facilities.
- Military housing on Tinker AFB is limited and is not in the vicinity of Landfills 1 through 4.

There were no sensitive subpopulations identified within the industrial site workers determined to represent the potentially exposed population at the sites.

The land use at and near the Base is not expected to change because the facilities have decades of useful life remaining and the Base has an important and continuing mission. Conversion of nearby land to residential use is improbable because of noise and safety concerns associated with such land use around an active airport.

The covered waste trenches are the source of contamination at Landfill 1. Potential groundwater contamination via migration of landfill leachate was not identified as a significant transport mechanism. It was determined that contamination of useable groundwater was not possible because of the great horizontal and vertical distances to groundwater use points, and the natural geophysical impediments to contaminant movement in the area. All homes in the area around and downgradient of Landfills 1 through 4 are served by municipal water. Therefore, the potential exposure route involving ingestion of contaminated groundwater was determined to be incomplete for current and future scenarios.

The only complete exposure pathways identified during the exposure assessment are inhalation of contaminated soil particles and inhalation of organic vapors from contaminated soil. A landfill cap was constructed over the buried wastes at Landfill 1 in March 1991 after the preliminary draft risk assessment was completed, and the future existence of this cap may not have been factored into the determination of exposure pathways.

A summary of the exposure pathways evaluated for potential receptors under current and future land use scenarios, and the rationale for inclusion or exclusion in the risk characterization is presented in Table 6-1.

6.2 Ecological Receptors

Tinker AFB lies within a grassland ecosystem, which is typically composed of grasses, forbes, and riparian (i.e., trees, shrubs, and vines associated with water courses) vegetation. This ecosystem has generally experienced fragmentation and disturbances as result of urbanization and industrialization at and near the Base. While no threatened or endangered plant species occur on the Base, the Oklahoma penstemon (*Penstemon oklahomensis*), identified as a rare plant under the Oklahoma Natural Heritage Inventory Program, thrives in several locations on Base. Tinker AFB policy considers rare species as if they were threatened or endangered and provides the same level of protection for these species.

In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base. However, one specie found on the Base, the Texas horned lizard (*Phrynosoma cornutum*), is a Federal Category 2 candidate specie and under review for consideration to be listed as threatened or endangered. Air Force policy (AFR 126-1) considers candidate species as threatened or endangered and provides the same level of protection.

The Oklahoma Department of Wildlife Conservation also lists several species within the state as Species of Special Concern. Information on these species suggests declining populations

Table 6-1

Summary of Complete Exposure Pathways
SWMUs 3-6, Landfills 1-4, Tinker AFB

Potentially Exposed Population	Exposure Route, Medium and Exposure Point	Pathways Selected for Evaluation?	Reason for Selection or Exclusion
Current Land Use			
Residents	Ingestion of groundwater from local wells downgradient.	No	Pathway is incomplete. All water is from municipal systems in areas downgradient from site.
Residents	Inhalation of contaminated particulates.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Inhalation of organic vapors.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Dermal contact with contaminated particulates.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Incidental ingestion of contaminated particles.	No	General public does not have access to facility or site. Pathway is incomplete.
Industrial workers	Inhalation of contaminated particles.	Yes	Workers will be present intermittently in adjacent facilities.
Industrial workers	Inhalation of organic vapors.	Yes	Workers will be present intermittently in adjacent facilities.
Industrial workers	Dermal contact with contaminated particles.	No	Workers will not be present on the site. Pathway is incomplete.
Industrial workers	Incidental ingestion of contaminated particles.	No	Workers will not be present on the site. Pathway is incomplete.
Future Land Use			
It is anticipated that there will be no long-term change in land use because the site is located on a defense installation that has a critical, continuing mission			

but information is inadequate to support listing, and additional monitoring of populations is needed to determine the species status. These species also receive protection by Tinker AFB as threatened or endangered species. Of these species, the Swainson's hawk (*Buteo swainsoni*) and the burrowing owl (*Athene cunicularia*) have been sighted on Tinker AFB. The Swainson hawk, a summer visitor and prairie/meadow inhabitant, has been encountered Basewide. The burrowing owl has been known to inhabit the Air Field at the Base.

7.0 Action Levels

An "action level" is defined by EPA in proposed rule 40 CFR 264.521 (55 FR 30798; 7/27/90), "Corrective Action for solid waste management Units (SWMU) at Hazardous Waste Management Facilities," as a health- and environment-based level, determined by EPA to be an indicator for protection of human health and the environment. In the preamble to this proposed rule, the focus of the RFI phase is defined as "characterizing the actual environmental problems at the facilities." As part of this characterization, a comparison of the contaminant concentrations to certain action levels should be made to determine if a significant release of hazardous constituents has occurred. This comparison is then used to determine if further action or corrective measures are required for a SWMU or an AOC. The preamble to the proposed rule states that the concept of action levels was introduced because of the need for "a trigger that will indicate the need for a Corrective Measures Study (CMS) and below which a CMS would not ordinarily be required" (55 FR 30798; 7/27/90). If constituent concentrations exceed certain action levels at a SWMU or an AOC, further action or a CMS may be warranted; if constituent concentrations are below action levels, a finding of no further action may be warranted. This chapter of the report presents the initial analytical data as compared to certain potential action levels.

Action levels are concentrations of contaminants at or below which exposure to humans or the environment should not produce acute or chronic effects.

The action level information is presented in this chapter so that a constituent concentration at a sample location can be compared with its potential action level. Only constituents identified in the analysis are listed in the SWMU-3, Landfill 1 table. Table 7-1 shows the action levels for soil, water, and air as published in federal or state regulations, policies, guidance documents, or proposed rules.

The action levels listed in Table 7-1 are:

- ***SWMU Corrective Action Levels (CAL)*** - The first set of action levels provided in the table are those taken from the proposed rule (40 CFR 264.521) and provided as Appendix A to the rule as "Examples of Concentrations Meeting Criteria for Action Levels." These levels are health-risk based and are provided

Table 7-1

Action Levels
SWMU-3, Landfill 1, Tinker AFB

(Page 1 of 2)

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air ($\mu g/m^3$)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air ($\mu g/m^3$)	WQS[e] Water (mg/L)
Volatile Organics							
1,1-Dichloroethene	10		0.03	0.007			
1,2-Dichloroethane	8.0		0.04	0.005			
1,1,2-Trichloroethane	100	0.006	0.6	0.005			
Acetone	8000	4.0					
Benzene				0.005			0.714
Chlorobenzene	2000	0.7	20	0.1			
Chloroform	100	0.006	0.04	0.1			4.708
Cis-1,2-dichloroethene	8		0.04	0.07			
Ethyl benzene	8000	4.0		0.7			28.72
Methylene chloride	90	0.005	0.3	0.005			
Styrene	20,000	7.0		0.1			
Tetrachloroethene	10	0.0007	1.0	0.005			
Toluene	20,000	10	7000	1.0			301.9
Trans-1,2-dichloroethene	8		0.04	0.1			
Trichloroethene	60			0.005			
Trichlorofluoromethane	20,000	10	700				
Vinyl chloride				0.002			
Xylenes (total)	2.0×10^5	70	1000	10			
Semivolatile Organics							
1,2-Dichlorobenzene				0.6			
1,4-Dichlorobenzene				0.075			
Bis(2-ethylhexyl)phthalate	50	0.003		0.006			
Butylbenzyl phthalate	20,000	7.0		0.1			

Table 7-1

(Page 2 of 2)

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air (μg/m³)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air (μg/m³)	WQS[e] Water (mg/L)
Semivolatile Organics (Continued)							
Chrysene				0.0002			
Diethyl phthalate	60,000	30					
Di-n-butyl phthalate	8000	4.0					
Metals							
Arsenic	80		7.0×10^{-5}	0.05	21		0.0014
Barium	4000		0.4	2	6400		
Cadmium	40		0.0006	0.005			0.0841
Chromium VI	400		9.0×10^{-5}				
Chromium				0.1	110		3.365
Lead				0.015[f]	27	1.5[g]	0.025
Mercury	20			0.002			0.0006
Nickel	2000	0.7		0.1	61		4.583
Selenium				0.05	1.2		
Silver	200						64.62
Zinc					79		
Cyanide	2000	0.7		0.2			
Radiometrics							
Gross Alpha				15 pCi/L			
Radium-226+Radium-228				20 pCi/L			

[a]CAL - Corrective Action Levels
[b]MCL - Maximum Contaminant Levels
[c]USGS - United States Geological Survey
[d]NAAQS - National Ambient Air Quality Standards
[e]WQS - Water Quality Standards
[f]Action Level at the Tap
[g]3 Month Average

as specific examples of levels below which corrective action would not be required.

- ***Maximum Contaminant Levels (MCL)* -** These values are provided from 40 CFR Subpart G, Sections 141.60 through 0.63 as promulgated under the Safe Drinking Water Act. These levels are designated for water media only.

- ***USGS Background* -** These values are provided from the USGS report titled "Elemental Composition of Surficial Materials from Central Oklahoma" (USGS, 1991). These values represent the levels of metals which naturally occur in Central Oklahoma soils.

- ***Background* -** These levels are provided where background could be determined. Where available, background concentrations are listed for metals in soil samples taken on site, which were thought to be unaffected by releases from a unit.

- ***National Ambient Air Quality Standards (NAAQS)* -** These standards are published in 40 CFR Part 50 under the Clean Air Act and apply to point sources that emit a limited number of constituents to the air. The constituents regulated are nitrogen dioxide, sulphur dioxide, carbon monoxide, lead, ozone, and particulate matter. Currently, it is assumed that none of the SWMUs or AOCs emit these compounds in regulated quantities and no air samples have been taken which would allow for a valid comparison.

- ***Water Quality Standards (WQS)* -** The WQS are the standards for surface water quality as established by the State of Oklahoma. These standards apply to point source discharges to surface waters and have been listed for those units adjacent to surface water.

8.0 Summary and Conclusions

Landfill 1 has a surface area of approximately 1.5 acres and is located in the southwest corner of Tinker AFB. The landfill is bordered by Crutcho Creek to the north and east, Patrol Road to the west, and Building 1022 to the south. Approximately 21,870 yd^3 of waste materials are estimated to have been deposited in the landfill between 1942 to 1945. The landfill received all solid and liquid wastes, including general refuse and industrial wastes. The site may have received waste solids from the domestic waste treatment plant. The waste was placed in unlined trenches running east to west across the site, and was typically burned to reduce the volume. The trenches extended to a depth of 10 to 25 feet, through a 6- to 8-foot clay layer into a sand/rock zone. The waste was covered daily with several inches of soil excavated during the landfill construction.

The USACE conducted a RI of Landfills 1 through 4 from 1986 to 1990. During the investigations at Landfill 1, borings (L1-1 and L1-2) were advanced into the soil and two soil samples were collected from these borings for analysis. The borings were placed in the former landfill trenches.

The analytical results from soil samples collected within the landfill were compared to action levels and background concentrations in the case of metals. Three organic compounds (methylene chloride, acetone, and di-n-butyl phthalate) were detected in the samples. None of the compounds were detected at concentrations exceeding action levels. Nine metals were detected within the soil samples. Cadmium and mercury were the only metals detected above naturally occurring background concentrations. No metals were detected at concentrations exceeding action limits.

The quality of USZ and LSZ groundwater in the vicinity of Landfill 1 was evaluated during the RI. Groundwater samples were collected from the boreholes drilled during the soils investigation, and monitoring wells surrounding the landfill were sampled. Three monitoring wells were screened in the USZ. Two monitoring wells were screened in the LSZ.

The water samples collected from the soil borings in the landfill trenches are representative of the quality of the USZ groundwater in this area of the landfill. The analytical results from groundwater samples collected in the USZ within the landfill were compared to the action levels developed in Chapter 7.0. Three VOCs (methylene chloride, acetone, and chloro-benzene) were detected in the samples. Methylene chloride was detected at a concentration of

370 µg/L, above its action level of 5 µg/L. Two SVOCs, diethyl phthalate and 4-methylphenol, were detected in the samples. Both compounds were detected at concentrations below their respective action limits. Twelve metals were detected in the groundwater samples. Five metals were detected above their action limits at the following concentrations: barium, 9,500 µg/L; cadmium, 210 µg/L; chromium, 650 µg/L; lead, 1,200 µg/L; and nickel, 270 µg/L. In addition, groundwater samples were submitted for gross alpha, gross beta, and total radium radiometric measurements. Only gross alpha readings were measured at levels which exceeded action levels.

Monitoring wells 1B, 2A, and 9A were sampled to determine the quality of USZ groundwater adjacent to the landfill. These wells were sampled during the RI groundwater investigation and continue to be sampled as part of the ongoing groundwater monitoring program at Tinker AFB. Sixteen VOCs were detected in the USZ monitoring well samples. Of the 16 VOCs detected, methylene chloride, trichloroethene, benzene, and vinyl chloride were detected at levels exceeding their respective action limits. Six SVOCs were detected in the samples. Bis(2-ethylhexyl)phthalate was the only SVOC detected above its action level. Twelve metals were detected in the samples. Metals detected above their respective action levels included barium, cadmium, chromium, lead, and nickel. In addition, four radiometric measurements were performed on the samples. The maximum measured gross alpha activity as 16.1 pCi/L, just above the action level of 15 pCi/L.

Monitoring wells 2B and 9B were sampled to determine the quality of LSZ groundwater adjacent to the landfill. These wells were sampled during the RI groundwater investigation and continue to be sampled as part of the ongoing groundwater monitoring program at Tinker AFB. Two VOCs were detected in the groundwater samples. Both 1,2-dichloroethene and trichloroethene were detected at concentrations above their respective action levels. Of the two SVOCs detected, bis(2-ethylhexyl)phthalate was the only SVOC detected above action levels. Seven metals were detected in the samples. Lead was the only metal found at concentrations above action levels. In addition, gross alpha activity was measured at levels exceeding action levels.

A preliminary comparison of the analytes detected in soil and groundwater within Landfill 1 versus USZ and LSZ monitoring wells around the landfill perimeter suggests that the landfill is not the source of at least a portion of the analytes detected in the USZ wells. Of the 18 VOCs detected, only 3 were detected within the landfill. In addition, six SVOCs detected in the USZ wells were not detected within the landfill. The existing data suggests that organic compounds, cadmium, mercury, and radioactive materials present in the landfill may potentially be leaching into the surrounding groundwater.

An interim remedial action to construct an 2-acre cap over Landfill 1 was completed in March 1991. A fence was installed around the cap to restrict access to the area and protect the integrity of the landfill cover. The cap was designed to RCRA standards. The purpose of this interim measure was two-fold:

- Minimize the migration of contaminated leachate to groundwater via infiltration of rainwater, thereby reducing the mobility of subsurface pollutants.

- Minimize surface soil erosion and landfill maintenance.

This interim measure was deemed to be appropriate, cost-effective, and protective of human health and the environment.

9.0 Recommendations

The following paragraphs describe additional work that is recommended to fully characterize the nature and extent of contamination and the risks to human health and the environmental at Landfill No. 1. Based on the location of this site, it will be more appropriate to investigate it as part of a group comprising several waste units in close proximity: RWDS 1030W, RWDS 1022E, RWDS 62598, Landfills 2 through 4, the SP, and FTA1. Details of specific sampling needs will be presented in the work plan/sampling plan for the Phase II RFI.

Review of Landfills 1 Through 4 RI Report. Upon comparison of the RI report summary tables of analytical results presented in Volume I and of the available laboratory results in Volumes 3 and 4 (USACE, 1993), numerous discrepancies were noted. A thorough review should be performed to resolve the discrepancies. The accuracy of these summary tables is crucial to the text of the RI. It was also noted that not all of the laboratory results were present to completely verify results listed in the summary tables.

In the previous investigations, data has been collected to characterize contaminated soils and groundwater within the landfill and investigate groundwater contamination around the perimeter of the landfill. A Phase II field investigation is recommended to perform the following tasks:

- Install additional monitoring wells in the HWBZ, USZ, and LSZ to characterize and determine the lateral and vertical extent of groundwater contamination originating from Landfill 1.
- Perform additional soil sampling around the landfill (outside the limits of the CAP) in areas where elevated levels of contaminants were detected to determine the extent of soil contamination.
- Perform aquifer testing to obtain data to evaluate potential transport and migration of contaminants.
- Perform a baseline risk assessment to assess potential impacts to human health and the environment.

Installation of Additional Groundwater Monitoring Wells. The current well control adjacent to Landfill 1 is limited to three wells completed in the USZ (MW-1B, 2A, 9A) and two wells completed in the LSZ (MW-2B and 9B). Monitoring well MW-1A is screened across the USZ and LSZ. It is recommended that MW-1A be abandoned because it does not meet the standards established in the *RCRA Ground-Water Monitoring Technical Enforcement Guidance Document* (EPA, 1986). Additional monitoring wells are needed to:

- Delineate and monitor the HWBZ and USZ separately as opposed to the USZ as currently defined in this report, which includes both zones.
- Determine the direction of localized groundwater flow within the HWBZ, USZ, and LSZ.
- Determine the extent of contamination in the LSZ.

Installation of two three-well clusters and one shallow well is recommended around the landfill. Each well cluster will include wells completed in the HWBZ, USZ, and LSZ. One well cluster will be positioned in the northeast corner of the landfill southeast of Crutcho Creek. The second well cluster will be located due south of the landfill. A shallow well completed in the HWBZ is recommended next to existing wells 9A and 9B. Every monitoring well will have a 10-foot screen unless geologic conditions require shorter screens. All monitoring wells will be added during the Phase II RFI as part of the basewide groundwater investigation. The proposed well configuration along with the existing wells will provide adequate well control to determine groundwater flow direction and background versus downgradient contaminant concentrations within all three zones.

All existing and newly installed wells should be sampled and submitted for laboratory analysis of VOCs, SVOCs, metals, inorganic parameters, and radionuclides.

Aquifer slug testing should be performed on some of the monitoring wells to obtain data to calculate groundwater flow rates. Slug tests should be performed at least in one upgradient and one downgradient well for each zone.

After the completion of the Phase II field investigation, a baseline risk assessment should be performed to evaluate potential threats to human health and the environment. The risk assessment should include both a human health and ecological assessment.

The effect of the RCRA cap on the local hydrology should be studied as part of an on-going monitoring process.

In addition, to fully evaluate the extent of soil contamination at this site it is recommended that site-specific soil background samples be collected during the Phase II RFI. This additional information along with the USGS background values should be used in the Phase II report to distinguish site-related from background concentrations in a statistically significant manner. During the development of the Phase II RFI work plan, the number of background samples to be collected, the location of the soil borings, and the soil analysis to be performed on the samples should be determined for EPA approval.

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Final Report
Phase I RCRA Facility Investigation for Appendix I Sites

VOLUME VII

SWMU-4, Landfill No. 2

Department of the Air Force
Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma

September 1994

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List of Acronyms

AFB	Air Force Base
AFSCAPS	Air Force Site Characterization and Analysis Penetrometer System
ARA	Applied Research Associates, Inc.
AOC	area of concern
B&V	B&V Waste Science and Technology Corporation
BTEX	benzene, toluene, ethyl benzene, and xylenes
CAL	corrective action levels
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/s	centimeters per second
DERP	Defense Environmental Restoration Program
DOD	U.S. Department of Defense
EID	Engineering Installation Division
EPA	U.S. Environmental Protection Agency
ES	Engineering Science
ft/ft	foot per foot
HARM	hazardous assessment rating methodology
HNu	photoionization
HSWA	Hazardous and Solid Waste Amendments
HWBZ	Hennessey water bearing zone
ILCR	incremental lifetime cancer risk
IRP	Installation Restoration Program
LIF-CPT	Lazer Induced Fluorescence Electronic Cone Penetrometer Test
LSZ	lower saturated zone
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
m^3	cubic meters
msl	mean sea level
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NPL	National Priorities List
PAH	polyaromatic hydrocarbons

PA/SI	preliminary assessment/site investigation
PCA	tetrachloroethane
PCB	polychlorinated biphenyl
PRC	Environmental Management, Inc.
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RI/FS	remedial investigation
RFI	RCRA Facility Investigation
ROD	Record of Decision
RWDS	Radioactive Waste Disposal Site
SARA	Superfund Amendments and Reauthorization Act
SGI	soil gas investigation
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TCE	trichloroethane
TOC	total organic carbon
TOX	total organic halogens
TPH	total petroleum hydrocarbons
TSD	treatment, storage, or disposal (facility)
USACE	U.S. Army Corps of Engineers
USC	U.S. Code
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USZ	upper saturated zone
UWBZ	upper water bearing zone
VOC	volatile organic compounds
yd^3	cubic yards

Executive Summary

This report provides a summary of the various investigations that have been conducted at solid waste management unit (SWMU)-4, Landfill No. 2 (Landfill 2), Tinker Air Force Base (AFB), Oklahoma. The report has been prepared to determine and document whether sufficient investigations at Landfill 2 have been performed to meet regulatory requirements. Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County. The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. The Base encompasses approximately 5,000 acres.

Background. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon™, jet fuels, and radium paints.

In 1984, Congress amended the Resource Conservation and Recovery Act (RCRA) with the Hazardous and Solid Waste Amendments (HSWA), which allow U.S. Environmental Protection Agency (EPA) to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or contaminants from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989, Tinker AFB submitted its Part B permit application for renewal of its operating RCRA Hazardous Waste Storage facility permit. The final RCRA HSWA permit issued on July 1, 1991, requires Tinker AFB to investigate all SWMUs and areas of concern (AOC) and to perform corrective action at those identified as posing a threat to human health or the environment. The permit specifies that a RCRA Facility Investigation (RFI) be conducted for 43 identified SWMUs and two AOCs on the Base. This document has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 2.

Source Description. Landfill 2 was in operation from 1945 to 1952. The landfill was used primarily for disposal of general refuse from the Base, including sanitary and industrial, along with unknown quantities of paints and solvents. The waste was disposed of in trenches approximately 20 feet in depth and 35 to 40 feet wide, in an east-west orientation. The refuse was covered daily with several inches of excavated native soil and completed trenches were covered with 3 to 4 feet of soil. One specific-use dump area was found in the northeast portion of the landfill during investigations. The material in the dump was composed primarily of industrial solvents and petroleum products. The southern end of Landfill 2 was utilized for a redrumming area. Leaky drums from various Base operations were stored and redrummed in this area. Drummed materials, including a solidified polymer and metal shavings, were found in the trenches on the southwestern edge of the Landfill 2. The trash found in the landfill was composed primarily of wood, metal, paper, rubber, and plastic materials. The quantity of waste placed in Landfill 2 was estimated to be approximately 603,387 cubic yards (yd^3).

The inactive Radiological Waste Disposal Site (RWDS) 1030W is located in the central portion of Landfill 2. The site was reported to be a burial for burned radium dial waste, including rags and solvent solution. The waste was dumped in a pit, then burned, and then a covering of soil was placed over the waste. Remediation of RWDS 1030W began in the spring of 1992 and has not been completed at this time. For additional information regarding this site, see the RCRA Facility Investigation Summary Report, SWMU-19, Radioactive Waste Disposal Site 1030W, April 1994 by IT Corporation.

Site Investigations. The initial phase of investigations performed at Tinker AFB was conducted by Engineering Science (ES) (1992). The purpose of this study was to conduct a records search for identification of past waste disposal activities to evaluate potential sources of contamination. ES concluded that Landfill 2 has a high potential for migration of contaminants; the site received a hazard assessment rating methodology (HARM) score of 65. ES recommended that Pistol Pond be drained to reduce the potential pathways for contaminant migration. For monitoring purposes, it was recommended that a geophysical survey be conducted; four lysimeters be installed on each side of the landfill; existing groundwater monitoring wells be sampled; and a background monitoring well be constructed.

IRP Phase II, Stage 1 field activities were initiated in 1983 by Radian Corporation (Radian, 1985a). The purpose of these activities was to determine if environmental contamination had occurred due to disposal and management practices at Landfill 2. Activities included an estimate of the magnitude and extent of contamination; the identification of environmental consequences of migrating pollutants; and the recommendation of additional investigations necessary to identify the magnitude, extent, and direction of movement of discovered contaminants. As part of the Stage 1 investigation, Radian installed three monitoring wells (1-A, 1-B, and 1-C) in the vicinity of Landfills 1 and 4. Radian's Phase II, Stage 2 (Radian, 1985b) field activities conducted from June through October 1984 focused on areas of contamination discovered during the Phase II, Stage 1 field work, and, therefore, did not involve any additional groundwater testing or soil borings at Landfill 2.

Tinker AFB employed the U.S. Army Corps of Engineers (USACE) between 1986 and 1990 to conduct a remedial investigation (RI) of Landfill 2 as part of the U.S. Air Force Installation Restoration Program (IRP). The USACE assessed the magnitude and extent of contamination originating in the Landfill 2 trenches. Investigations on Landfill 2 involved trench waste characterization, a sludge dump investigation, investigations to establish both the southeast and southwest boundaries of the landfill, and a soil gas survey. From December 1986 to February 1987, ten soil borings (boring L2-1 through L2-10) were drilled across the trench area. Soil samples of the cover material were collected from the borings with split-spoons or Shelby tubes, and composited samples of the waste were collected from the auger flights. The consolidated shales, siltstones, and sandstones underlying the overburden material were sampled using a 4-inch core barrel in selected locations. Polyvinyl chloride (PVC) pipes were installed in the boreholes where water was encountered.

In June 1989, four additional soil borings (borings L2-11 through L2-14) were drilled along the eastern edge of Landfill 2 to better define the landfill boundary. A specific-use sludge dump was discovered at boring L2-11, in the northeastern corner of the landfill. Borings L2-12, L2-13, and L2-14 were drilled in the southeastern edge of the landfill. No wastes were encountered in these three borings, so the landfill boundary was revised to exclude this area. This modification placed the southeast corner of Landfill 2 approximately 300 feet west of Reserve Road; previously the corner had been immediately adjacent to the road. The area surrounding boring L2-9 was not excluded from the landfill because of evidence of trenches in the area on historical aerial photographs.

As previously discussed, boring L2-11 indicated a specific-use sludge dump located in the northeastern corner of the landfill. High concentrations of industrial solvents and hydrocarbons were detected in the collected samples. Records were not available on the type of material deposited in this area; an investigation was performed to characterize the sludge material encountered. A truck-mounted, auger-type drilling rig was utilized to collect soil and sludge samples in the vicinity of the sludge material. Borings in this area revealed a black, sludge-like material. A follow-up investigation was conducted in the vicinity of the sludge dump to determine the lateral and vertical limits of the sludge dump and to further characterize the contaminants present.

An investigation was conducted in April 1990 on Landfills 2 and 4 to provide definition of the southwest boundary of Landfill 2. The boundary investigation was conducted in connection with the design of landfill cover system for Landfill 2. A series of 42 soil borings (borings L4-12A to L4-29C) were drilled along the southwestern edge of Landfill 2 and the southern edge of Landfill 4. References provided in the USACE RI (USACE, 1993; Drawing No. 1, Map of Explorations, and Appendix B, Geologic Logs) do not provide adequate information to determine the association of the borings to the respective landfill. Soil samples were collected and placed in one-half quart glass jars for ambient head space analysis. Field screening of the samples was accomplished with Draeger tubes and an photoionization (HNu) meter for detection of contamination originating from Landfill 2 in the shallow subsurface soils. The Draeger tubes were utilized for analysis of vinyl chloride, acetone, and trichloroethane.

Tinker AFB employed B&V Waste Science and Technology Corporation (B&V) in 1989 to evaluate alternative cover systems for Landfill 2 and investigate the need to relocate utility systems within the vicinity of the landfill. B&V recommended a natural soil cover with synthetic water barrier and gas control layers. In 1992, B&V issued a pre-final design analysis and construction specifications for the selected cover at Landfill 2.

The USACE employed Tracer Research Corporation to conduct a shallow soil gas investigation (SGI) at Landfills 2 and 4 in July 1989 and March 1990. The purpose of the SGI was to define the nature and extent of volatiles present in the subsurface, and to assist in determining the placement of borings for additional soil and groundwater investigations. A total of 114 soil/gas samples were collected for the two landfills. The samples were analyzed for the following target compounds:

- 1,1,1-Trichloroethane
- Trichloroethene
- Tetrachloroethane
- Methane
- Benzene, toluene, ethyl benzene, and xylene (BTEX)
- Total petroleum hydrocarbons (TPH).

The 1989 results of the SGI in the vicinity of L2-11 showed only benzene, toluene, and TPH at significant levels. An SGI was conducted on the landfill in March 1990 to obtain qualitative information on the gases evident on the landfill surface. The results of the SGI indicated areas of localized contamination on Landfill 2 for all of the screened compounds, except for methane. Methane was detected consistently across the landfill area, with concentrations decreasing rapidly at the Landfill 2 boundaries.

The U.S. Air Force employed Applied Research Associates, Inc. (ARA) in 1992 to demonstrate the effectiveness of a prototype Laser Induced Fluorescence-Electronic Cone Penetrometer Test (LIF-CPT) system in site characterization at Tinker AFB. From March to November, ARA investigated eight test areas, including Landfill 2. CPT soundings were completed at 112 locations and the LIF sensor was used at 81 locations. Eleven CPT profiles were performed in Landfill 2 near the sludge dump boring L2-11. Eight soil samples and five groundwater samples were collected for on-site analysis. Four soil samples and five groundwater samples were collected for off-site analysis. The soil samples were void of any volatile organic compounds (VOC) and semivolatile organic compounds (SVOC). Heavy metals were found in high concentrations in all soil samples. LIF profiling was conducted at seven CPT locations. The LIF became inoperable after the seventh profile and was not used further at Landfill 2. None of the profiles had LIF values above baseline values.

Conclusions. Soil and groundwater samples collected have been analyzed for VOCs, SVOCs, metals, indicator parameters, pesticides, and PCBs. Groundwater samples were also analyzed for radiometric parameters. An evaluation of the data to establish constituents of potential concern has not been performed. However, contaminant concentrations were compared to health and environment-based action levels. The action levels included SWMU corrective action levels (CAL), maximum contaminant levels (MCL), and water quality standards (WQS) derived from federal and state regulations.

Eight VOCs and five SVOCs were detected in landfill trench soils, but none at concentrations exceeding their respective action levels. Nine metals were detected in the soil samples. Only arsenic, cadmium, mercury, lead, silver, and zinc were detected at concentrations above background. Cadmium was the only metal detected at concentrations exceeding action levels.

Five VOCs and three SVOCs were detected in sludge dump soil samples, but none at concentrations exceeding their respective action levels. Ten metals were detected in the samples. Calcium, copper, nickel, silver, and zinc were detected at concentrations above background. No metals were detected at concentrations above action levels. The pesticide heptachlor was detected in a single sample, but at a concentration below its action level. In addition, cyanide was detected in one soil sample at a concentration below its action level.

Ten VOCs and four SVOCs were detected in the water samples collected from trench borings. Trichloroethene, vinyl chloride, trans-1,2-dichloroethene, and chlorobenzene were the only organic compounds detected at concentrations above their action levels. Eleven metals were detected in the samples. Barium, cadmium, chromium, lead, and nickel were all detected at concentrations exceeding their respective action levels. In addition, both gross alpha and total radium measurements exceeded action levels.

Six VOCs and two SVOCs were detected in sludge dump water samples. Benzene, methylene chloride, and bis(2-ethylhexyl)phthalate were the only organic compounds detected at concentrations above action levels. Fifteen metals were detected in the water samples. Barium, cadmium, and lead were the only metals detected at concentrations exceeding action levels. Both gross alpha and total radium measurements exceeded action levels.

Monitoring wells 5A, 60A, 79B, and 84B were sampled to determine the quality of USZ groundwater adjacent to the landfill. These wells were sampled during the RI groundwater investigation and continue to be sampled as part of the ongoing groundwater monitoring program at Tinker AFB. Twelve VOCs were detected at concentrations exceeding their analytical method detection limits. Trichloroethene, 1,2-dichloroethane, methylene chloride, tetrachloroethene, and 1,1-dichloroethene were detected at concentrations above their respective action levels. Five SVOCs were detected in the samples, but only bis(2-ethylhexyl)phthalate was detected above its action level. Eleven metals were detected in the samples. Chromium, lead, and nickel were the only metals detected above their action levels. Water samples were measured for radiometric readings, but none were measured at levels above action levels.

Monitoring wells 60B, 79C, 84C, and 4B are completed within the LSZ. The wells were sampled to investigate the quality of water within the LSZ adjacent to the landfill. Fourteen VOCs were detected to concentrations above their analytical method detection limits. Benzene, methylene chloride, and trichloroethene were the only VOCs detected above their action levels. Three SVOCs were detected, but only bis(2-ethylhexyl)phthalate was detected above its action level. Of the ten metals detected in the water samples, only arsenic, barium, and lead were detected at concentrations exceeding action levels. No radiometric readings in excess of action levels were measured.

No interim remedial actions have been completed at Landfill 2, but the design for a 28-acre landfill cap was completed in September 1992 and is not scheduled for installation. The landfill cap will require the rerouting of underground gas, water, sanitary sewer lines, and overhead power lines located in the southern portion of Landfill 2. Further investigation of the site will be conducted and EPA approval obtained before any remedial action.

Recommendations. The following are recommended to be implemented during Phase II investigations under the RFI program:

- A thorough review of the RI summary tables presenting analytical results and the laboratory results should be performed to resolve discrepancies. Not all of the laboratory results were present in the appendices of the RI. These results need to be added for verification of summary table results.

- Collect site-specific soil background samples to be used in addition to USGS soil data to distinguish site-related from background concentrations in a statistically significant manner during the Phase II investigation.

- Install additional soil borings to characterize the contaminated vadose zone soils within Landfill 2 and determine the extent of soil contamination.

- Install additional groundwater monitoring wells in the HWBZ, USZ, and LSZ to characterize and determine the lateral and vertical extent of groundwater contamination originating from Landfill 2. The wells should be sampled for VOCs, SVOCs, metals, inorganic parameters, and radionuclides.

- Perform aquifer slug tests on selected wells to obtain data to determine groundwater flow rates and evaluate potential migration of contaminants.

- Perform a baseline risk assessment to assess potential impacts to human health and the environment. The assessment should include both human health and ecological assessment.

1.0 Introduction

1.1 Purpose and Scope

This document has been prepared in response to the U.S. Department of the Air Force, Tinker Air Force Base (AFB), Oklahoma request for a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Summary Report for solid waste management unit (SWMU)-4, Landfill No. 2 (Landfill 2).

The objective of this RFI Summary Report is to provide Tinker AFB with one comprehensive report that summarizes the various investigations that have occurred at Landfill 2 since the first environmental investigation was initiated on Base in 1981. The purpose of this comprehensive summary document is to:

- Characterize the site (Environmental Setting).
- Define the source (Source Characterization).
- Define the degree and extent of contamination (Contamination Characterization).
- Identify actual or potential receptors.
- Identify all action levels for the protection of human health and the environment.

Additionally, this document briefly describes the procedures, methods, and results of all previous investigations that relate to Landfill 2 and contaminant releases, including information on the type and extent of contamination at the site, and actual or potential receptors. Where previous investigations, reports, or studies were not comprehensive and did not furnish the information required to determine the nature and extent of contamination, future work that can be conducted to complete the investigation has been recommended.

1.2 Preface

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to address the cleanup of hazardous waste disposal sites across the country. CERCLA gave the president authority to require responsible parties to remediate the sites or to undertake response actions through use of a fund (the Superfund). The president, through Executive Order 12580, delegated the U.S. Environmental Protection Agency (EPA) with the responsibility to investigate and remediate private party hazardous waste disposal sites that created a threat to human health and the environment. The president delegated responsibility for investigation and cleanup of federal facility disposal sites to the various federal agency heads. The Defense Environmental Restoration Program (DERP) was formally

established by Congress in Title 10 U.S. Code (USC) 2701-2707 and 2810. DERP provides centralized management for the cleanup of U.S. Department of Defense (DOD) hazardous waste sites consistent with the provisions of CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations [CFR] 300), and Executive Order 12580. To support the goals of DERP, the Installation Restoration Program (IRP) was developed to identify, investigate, and clean up contamination at installations.

Under the Air Force IRP, Tinker AFB began a Phase I study similar to a preliminary assessment/site investigation (PA/SI) in 1981 (Engineering Science [ES], 1982). This study helped locate 14 sites that needed further investigation. A Phase II study was performed in 1983 (Radian Corporation [Radian], 1985a, b).

In 1986, Congress amended CERCLA through SARA. SARA waived sovereign immunity for federal facilities. This act gave EPA authority to oversee the cleanup of federal facilities and to have the final authority for selecting the remedial action at federal facilities placed on the National Priorities List (NPL) if the EPA and the relevant federal agency cannot concur in the selection. Congress also codified DERP (SARA Section 211), establishing a fund for the DOD to remediate its sites because the Superfund is not available for the cleanup of federal facilities. DERP specifies the type of cleanup responses that the fund can be used to address.

In response to SARA, the DOD realigned its IRP to follow the investigation and cleanup stages of the EPA:

- PA/SI
- Remedial investigation/feasibility study (RI/FS)
- Record of Decision (ROD) for selection of a remedial action
- Remedial design/remedial action.

In 1984, Congress amended RCRA with the Hazardous and Solid Waste Amendments (HSWA) which allow the EPA to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or constituents from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989 Tinker AFB submitted its Part B permit application for renewal of its operating RCRA hazardous waste storage facility permit.

EPA, in the Hazardous Waste Management Permit for Tinker AFB, dated July 1, 1991, identified 43 SWMUs and two areas of concern (AOC) on Tinker AFB that need to be addressed. This permit requires Tinker AFB to investigate all SWMUs and AOCs and to perform corrective action at those identified as posing a threat to human health or the environment. This RFI Summary Report has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 2 and to document all determinations.

1.3 Facility Description

Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County (Figure 1-1) with its approximate geographic center located at 35° 25' latitude and 97° 24' longitude (U.S. Geological Survey [USGS], 1978). The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. An additional area east of the main Base is used by the Engineering Installation Division (EID) and is known as Area D. The Base encompasses approximately 5,000 acres. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon™, jet fuels, and radium paints. Wastes that are currently generated are managed at two permitted hazardous waste storage facilities. However, prior to enactment of RCRA, industrial wastes were discharged into unlined landfills and waste pits, streams, sewers, and ponds. Past releases from these landfills, pits, etc., as well as from underground tanks, have occurred. As a result, there are numerous sites of soil, groundwater, and surface water contamination on the Base.

The various reports generated as a result of investigative activities conducted at the Landfill 2 have been reviewed and evaluated in terms of the sites' status under RCRA regulations. A summary based on the review of these reports for Landfill 2 is presented in the following chapters and sections. In addition, recommendations for additional work is given at the end of the summary report.

1.4 Site Description

Landfill 2 is the largest of the four landfills in the Landfills 1 through 4 (SWMUs 3 through 6) site, which is located in the southwest corner of the Base. The landfill has a surface area

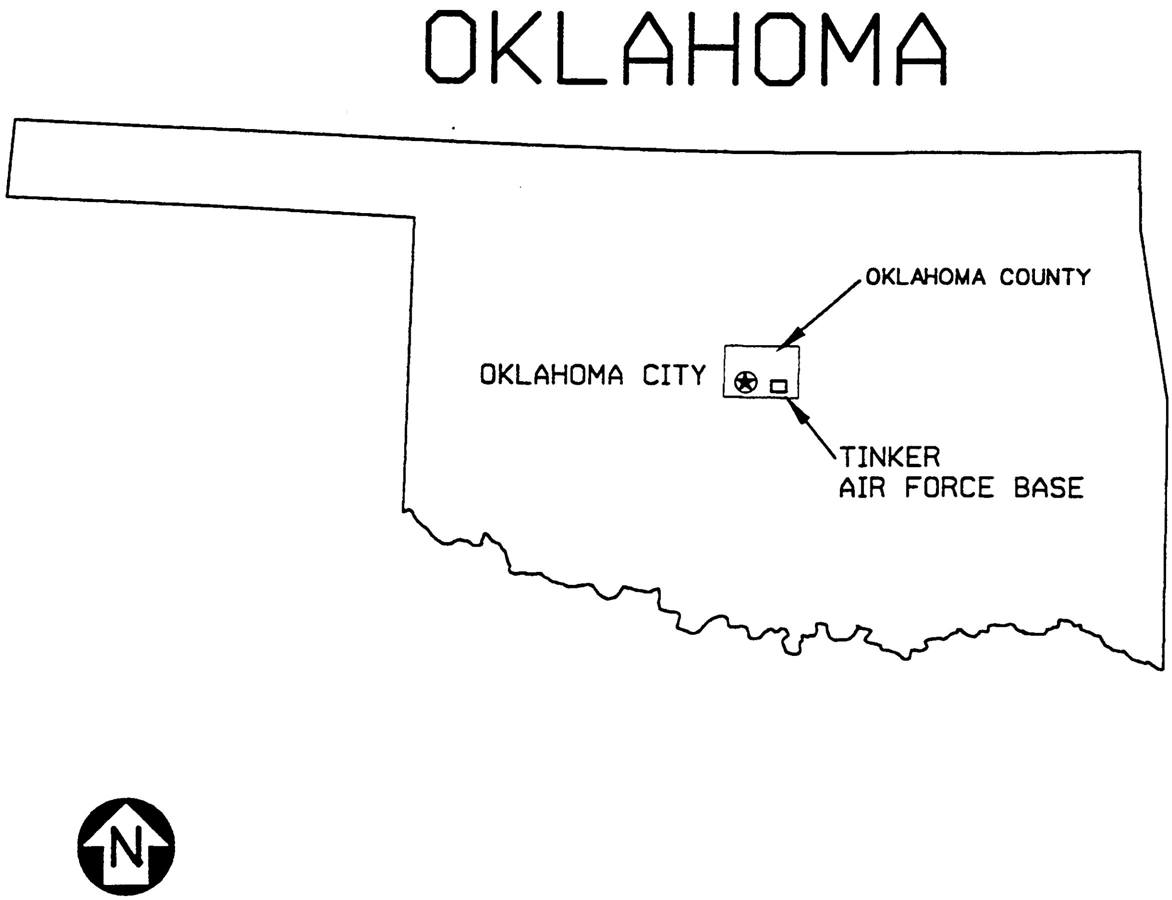

FIGURE 1-1
TINKER AIR FORCE BASE
OKLAHOMA
STATE INDEX MAP

PREPARED FOR
TINKER AFB
OKLAHOMA

STARTING DATE: 03/17/94 | DATE LAST REV.: | DRAFT. CHCK. BY:G. PACHECO | INITIATOR: C. WALLACE | DWG. NO.:
DRAWN BY:P.O. TERRY | DRAWN BY: | ENGR. CHCK. BY: C. WALLACE | PROJ. MGR.:J. TAYLOR | PROJ. NO.:

3/23/94 POT
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of approximately 27.5 acres and is bordered by Reserve Road to the east, Landfill Road to the north, and by Landfill 4 to the west. Landfill 2 was closed to landfill operations in 1952, and the completed trenches were covered with 3 to 4 feet of excavated native soil. Underground gas, water, sanitary sewer lines, and overhead power lines are located in the southern section of the landfill. The location of Landfill 2 relative to the Base is shown in Figure 1-2.

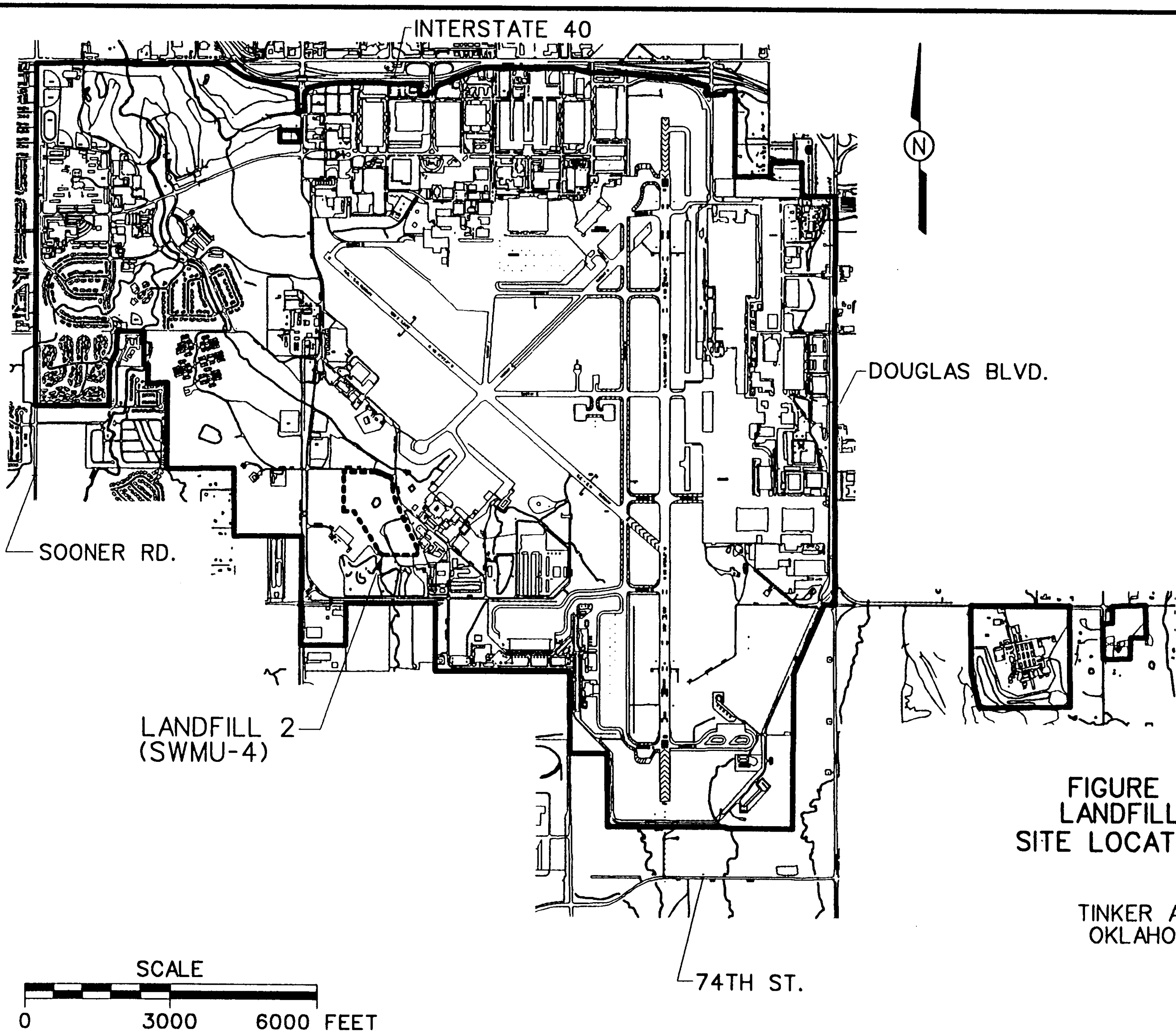


FIGURE 1-2
LANDFILL 2
SITE LOCATION MAP

TINKER AFB
OKLAHOMA

STARTING DATE: 3/21/94	DATE LAST REV.:	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P.O. TERRY	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

FILENAME: G:\TINKER\40983202.082

2.0 Background

2.1 Site Operations and History

Tinker AFB was originally known as the Midwest Air Depot and began operations in July 1941. The site was activated March 1942. During World War II, the depot was responsible for reconditioning, modifying, and modernizing aircraft, vehicles, and equipment.

Refuse generated from these operations has been disposed of in at least six landfills located on the Base property or leased land adjacent to the Base. One of these landfills, Landfill 2, is located in the southwest corner of the Base.

After closure of Landfill 1, Landfill 2 was opened. Landfill 2 was operated from 1945 to 1952. This landfill was used primarily for disposal of general refuse from the Base, including sanitary and industrial, along with unknown quantities of paints and solvents. The waste was disposed of in trenches approximately 20 feet in depth and 35 to 40 feet wide, in an east-west orientation. The refuse was covered daily with several inches of excavated native soil and completed trenches were covered with 3 to 4 feet of soil. One specific-use dump area was found in the northeast portion of the landfill during investigations. The material in the dump was composed primarily of industrial solvents and petroleum products. The southern end of the landfill was utilized for a redrumming area. Leaky drums from various base operations were stored and redrummed in this area. Drummed materials, including a solidified polymer and metal shavings, were found in the trenches on the southwestern edge of Landfill 2. The trash found in the landfill was composed primarily of wood, metal, paper, rubber, and plastic materials. The quantity of waste placed in Landfill 2 was estimated to be approximately 603,387 cubic yards (yd^3).

The inactive Radiological Waste Disposal Site (RWDS) 1030W (SWMU-19) is located in the central portion of Landfill 2. RWDS 1030W was reported to be a burial for burned radium dial waste, including rags and solvent solution. The waste was dumped in a pit, then burned, and then a covering of soil was placed over the waste. Remediation of RWDS 1030W began in the spring of 1992 and has not been completed at this time. Additional information regarding this site can be found in the RCRA Facility Investigation Summary Report, SWMU-19, Radioactive Waste Disposal Site 1030W, April 1994 by IT Corporation. The western portion of Landfill 2 consisted of rugged, slopping terrain with mixed vegetation. Erosion was apparent in some localized areas. A former recreation pond, Pistol Pond, was located on the eastern half of Landfill 2. The pond area was drained in 1986. Most of the surface water on the landfill discharges to the pond area; however, the pond retains little water except for a depressed area in the northwest portion of the pond that fills during periods of precipitation. The pond area drains to Crutcho Creek through a culvert under Landfill Road. The remainder of the surface water runoff discharges ultimately into Crutcho Creek. Methane gas emissions were evident across the surface of the landfill where, during periods of precipitation, the gas could be seen bubbling from the ground. Localized areas of leachate discharges were evident across the landfill especially along the slopes. These leachate areas have produced areas void of vegetation across the landfill. Rapcon Road intersects the southeast portion of the landfill and provides access to the FAM CAMP Recreation Area. In 1986 and 1987, the pond in the FAM CAMP area was dredged, and the material was placed on the north-central section of Landfill 2. Therefore, trench depressions are not evident in this area on current topographic maps. Underground gas, water, sanitary sewer lines, and overhead power lines are located in the southern section of Landfill 2.

The design of a 28-acre landfill cap for Landfill 2 was completed in September 1992 and is not scheduled for installation. The design and construction of a leachate collection and treatment system is also projected as a future interim action (Tinker, 1992).

2.2 Summary of Previous Investigations

Engineering Science - Phase I. Landfill 2 was among 14 of the individual sites identified for the Phase I studies for the Tinker AFB IRP. The studies were completed by ES in April 1982. The Phase I study conducted a records search for the identification of past waste disposal activities to evaluate potential sources of contamination.

ES concluded that Landfill 2 has a high potential for migration of contaminants; the site received a hazard assessment rating methodology (HARM) score of 65. ES recommended that Pistol Pond be drained to reduce the potential pathways for contaminant migration. For monitoring purposes, it was recommended that a geophysical survey be conducted; four lysimeters be installed on each side of the landfill; existing groundwater monitoring wells be sampled; and a background monitoring well be constructed.

Radian Corporation - IRP. IRP Phase II, Stage 1 field activities were initiated in 1983 by Radian (Radian, 1985a). The purpose of these activities was to determine if environmental contamination had occurred due to disposal and management practices at Landfill 2.

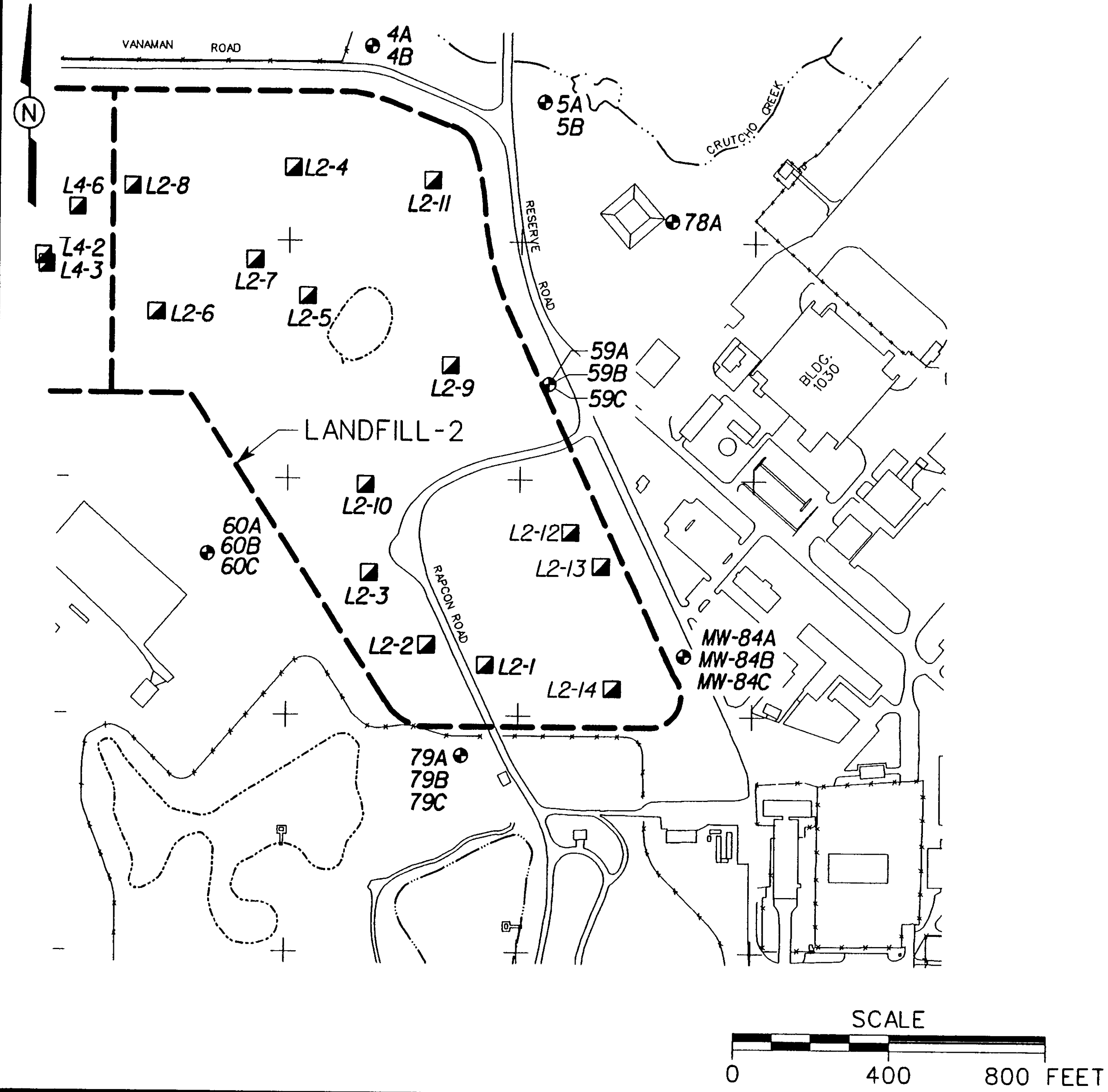
Activities included an estimate of the magnitude and extent of contamination; the identification of environmental consequences of migrating pollutants; and the recommendation of additional investigations necessary to identify the magnitude, extent, and direction of movement of discovered contaminants.

As part of the Stage 1 investigation, Radian installed three monitoring wells (1-A, 1-B, and 1-C) in the vicinity of Landfills 1 and 4. These wells, along with existing monitoring wells 1 through 5 located south of Crutcho Creek and northeast of Landfills 1, 2, and 3, indicated that the depth to groundwater ranged from 4 to 50 feet below the ground surface in the vicinity of the landfills. This finding either reflects the general topography in the area of Landfills 1 through 4 or the presence of multiple saturated zones penetrated by wells screened at different depths. Water levels were highest near Crutcho Creek, which borders Landfill 1 to the northeast. An exploratory boring was drilled east of Landfill 2 to a depth of 150 feet. Three hours after drilling advanced to total depth, the water level was observed at 55 feet below the land surface.

A surface water sample was collected from Pistol Pond, which did not display elevated levels of contaminants. Radian concluded that the pond was a driving hydraulic head for recharge through the landfill and resultant leaching of landfill materials.

Radian's Phase II, Stage 2 field activities conducted from June through October 1984 focused on areas of contamination discovered during the Phase II, Stage 1 field work, and, therefore, did not involve any additional groundwater testing or soil borings at Landfill 2.

U.S. Army Corps of Engineers (USACE). Tinker AFB employed the USACE between 1986 and 1990 to conduct a remedial investigation (RI) of Landfill 2 as part of the U.S. Air Force IRP. The USACE assessed the magnitude and extent of contamination originating in the Landfill 2 trenches. Investigations on Landfill 2 involved trench waste characterization, a sludge dump investigation, investigations to establish both the southeast and southwest boundaries of the landfill, and a soil gas survey. From December 1986 to February 1987, ten soil borings (boring L2-1 through L2-10) were drilled across the trench area. The locations of soil borings and groundwater monitoring wells are shown in Figure 2-1. Soil samples of the cover material were collected from the borings with split-spoons or Shelby tubes, and composited samples of the waste were collected from the auger flights. The consolidated shales, siltstones, and sandstones underlying the overburden material were sampled using a 4-inch core barrel in selected locations. Polyvinyl chloride (PVC) pipes were installed in the



LEGEND:

MW-59A MONITORING WELL

L2-7 SOIL BORING

FIGURE 2-1

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 2
SAMPLE LOCATION MAP

STARTING DATE: 01/15/94	DATE LAST REV.: / /	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: LLS	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

9/29/94 POT
FILENAME:C:\TINKER\40983202.127

boreholes where water was encountered. These borings included location numbers L2-1, L2-2, L2-3, L2-4, L2-5, L2-6, L2-7, L2-8, and L2-10. Boring L2-9 was a dry hole, and no visible wastes were encountered during drilling, so no samples were taken from this boring.

In June 1989, four additional soil borings (borings L2-11 through L2-14) were drilled along the eastern edge of Landfill 2 to better define the landfill boundary. A specific-use sludge dump was discovered at boring L2-11, in the northeastern corner of the landfill. Borings L2-12, L2-13, and L2-14 were drilled in the southeastern edge of the landfill. No wastes were encountered in these three borings, so the landfill boundary was revised to exclude this area. This modification placed the southeast corner of Landfill 2 approximately 300 feet west of Reserve Road; previously the corner had been immediately adjacent to the road. The area surrounding boring L2-9 was not excluded from the landfill because of evidence of trenches in the area on historical aerial photographs.

As previously discussed, boring L2-11 indicated a specific-use sludge dump located in the northeastern corner of the landfill. High concentrations of industrial solvents and hydrocarbons were detected in the samples collected. Records were not available on the type of material deposited in this area; an investigation was performed to characterize the sludge material encountered. A truck-mounted, auger-type drilling rig was utilized to collect soil and sludge samples in the vicinity of the sludge material. Borings in this area revealed a black, sludge-like material. A follow-up investigation was conducted in the vicinity of the sludge dump to determine the lateral and vertical limits of the sludge dump and to further characterize the contaminants present. This investigation involved the drilling of multiple boreholes in the immediate vicinity of the original boring, L2-11. In May 1990, 19 borings (borings L2-11-1 through L2-11-19) were drilled in six directions, radially from the L2-11 location where the sludge was first encountered, until a location void of any sludge material contamination was established. PVC pipes were installed in six of the borings to allow for the collection of water samples. Soil/sludge samples were collected for field screening by ambient head space analysis using Draeger® tubes and a photoionization (HNu®) meter, and representative samples of the sludge material and soils were collected for laboratory analysis. The field screening samples were composite samples collected from the auger flights.

During the investigation in May 1990, nine soil samples were collected from the borings and sent to the laboratory for chemical analysis. The soil/sludge samples were collected from borings L2-11-1, L2-11-5, L2-11-6, L2-11-8, L2-11-9, L2-11-10, L2-11-12, and L2-11-18, at depths ranging from 4 to 12.5 feet. PVC pipes were installed in six of the borings, at locations L2-11-1, L2-11-6, L2-11-8, L2-11-9, L2-11-12, and L2-11-19. Water samples were collected from these PVC pipes on July 10, 1990.

An investigation was conducted in April 1990 on Landfills 2 and 4 to provide definition of the southwest boundary of Landfill 2. The boundary investigation was conducted in connection with the design of landfill cover system for Landfill 2. A series of 42 soil borings (borings L4-12A to L4-29C) were drilled along the southwestern edge of Landfill 2 and the southern edge of Landfill 4. References provided in the USACE RI (USACE, 1993; Drawing No. 1, Map of Explorations, and Appendix B, Geologic Logs) do not provide adequate information to determine the association of the borings to the respective landfill. Soil samples were collected and placed in one-half quart glass jars for ambient head space analysis. Field screening of the samples was accomplished with Draeger tubes and an HNu meter for detection of contamination originating from Landfill 2 in the shallow subsurface soils. The Draeger tubes were utilized for analysis of vinyl chloride, acetone, and trichloroethane.

Encounters with wastes or contamination, as indicated by the Draeger tubes and HNu meter results, warranted the location of the borings outward from the existing Landfill 2 trenches until a line of borings void of any field detectable contamination was established.

B&V Waste Science and Technology Corporation. Tinker AFB employed B&V in 1989 to evaluate alternative cover systems for Landfill 2 and investigate the need to relocate utility systems within the vicinity of the landfill. B&V recommended a natural soil cover with synthetic water barrier and gas control layers.

In 1992, B&V issued a pre-final design analysis and construction specifications for the selected cover at Landfill 2. The cover system consisted of the following layers in order of construction placement:

- Fill layer to achieve the basic 3 to 5 percent initial slope and drainage patters
- Gas collection layer consisting of a synthetic drainage composite, or two layers of filter fabric sandwiched around a synthetic drainage net
- A 6-inch layer of compacted clay meeting the permeability specification of 1×10^{-7} centimeters per second (cm/s) or less

- A geosynthetic composite liner consisting of either a sandwich of filter fabric around a bentonite layer, or a bentonite layer attached to a flexible membrane liner

- A 40-mil flexible membrane liner

- A synthetic drainage net

- Filter fabric

- A 24-inch layer of fill material used to protect other cover components

- Six inches of topsoil with vegetation.

Tracer Research Corporation. The USACE employed Tracer to conduct a shallow soil gas investigation (SGI) at Landfill 2 and Landfill 4 in July 1989 and March 1990. The purpose of the SGI was to define the nature and extent of volatiles present in the subsurface, and to assist in determining the placement of borings for additional soil and groundwater investigations. A total of 114 soil/gas samples were collected for the two landfills. The samples were analyzed for the following target compounds:

- 1,1,1-Trichloroethane
- Trichloroethene
- Tetrachloroethane)
- Methane
- Benzene, toluene, ethyl benzene, and xylene (BTEX)
- Total petroleum hydrocarbons (TPH).

The 1989 results of the SGI in the vicinity of L2-11 showed only benzene, toluene, and TPH at significant levels. An SGI was conducted on the landfill in March 1990 to obtain qualitative information on the gases evident on the landfill surface. The results of the SGI indicated areas of localized contamination on Landfill 2 for all of the screened compounds, except for methane. Methane was detected consistently across the landfill area, with concentrations decreasing rapidly at the Landfill 2 boundaries. Methane concentrations in the ambient air samples collected near the surface of Landfill 2 were in the 1 to 2 micrograms per liter (μg/L) range, while the maximum concentration of methane found in the shallow soil was 18,000 μg/L, found on the western edge of Landfill 2 near the Landfill 4 boundary (Tracer, 1990). Information derived from this study was utilized in the ongoing design of a cover system for Landfill 2.

Applied Research Associates, Inc. (ARA). The U.S. Air Force employed ARA in 1992 to demonstrate the effectiveness of a prototype Laser-Induced Fluorescence-Electronic Cone Penetrometer Test (LIF-CPT) system in site characterization at Tinker AFB. From March to November, ARA investigated eight test areas, including Landfill 2. CPT soundings were completed at 112 locations and the LIF sensor was used at 81 locations. Eleven CPT profiles were performed in Landfill 2 near the sludge dump boring L2-11. Eight soil samples and five groundwater samples were collected for on-site analysis. Four soil samples and five groundwater samples were collected for off-site analysis. The soil samples were void of any volatile organic compounds (VOC) and semivolatile organic compounds (SVOC). Heavy metals were found in high concentrations in all soil samples. Most notable were arsenic, barium, cadmium, lead, and zinc. The high metals content is typical of ash or sludge materials. Water samples from existing piezometers were taken and analyzed for VOCs. Only the original piezometer (L2-11) had detectable quantities; benzene and toluene were measured at 168 and 27 μg/L, respectively.

LIF profiling was conducted at seven CPT locations. The LIF became inoperable after the seventh profile and was not used further at Landfill 2. None of the profiles had LIF values above baseline values.

2.3 Current Regulatory Status

The IRP has been ongoing at Tinker AFB since the early 1980s. IRP studies on the Base were conducted according to IRP guidance, which is essentially the same as EPA's guidance for conducting RI/FS under CERCLA. All investigation and removal actions have been closely monitored and approved by the EPA.

Since receiving the Hazardous Waste Management Permit on July 1, 1991, many of the IRP sites have come under the jurisdiction of the RCRA permits branch of EPA. As such, they have been identified as SWMUs; however, a large amount of work has already been performed at most of these sites under the IRP. Additional investigation at the SWMUs will be performed under the IRP.

3.0 Environmental Setting

3.1 Topography and Drainage

3.1.1 Topography

Regional/Tinker AFB. The topography of Oklahoma City and surrounding area varies from generally level to gently rolling in appearance. Local relief is primarily the result of dissection by erosional activity or stream channel development. At Oklahoma City, surface elevations are typically in the range of 1,070 to 1,400 feet mean sea level (msl). At Tinker AFB, ground surface elevations vary from 1,190 feet msl near the northwest corner where Crutcho Creek intersects the Base boundary to approximately 1,320 feet msl at Area D (EID).

Site. Landfill 2 is located on the southwest corner of Tinker AFB. The elevation ranges from 1,242 feet msl at boring L2-1 located in the southern area of the landfill to 1,248 feet msl at boring L2-8 near the western boundary of the landfill and 1,239 feet msl at boring L2-11 in the northeast corner of the landfill. The western portion of Landfill 2 consisted of rugged, slopping terrain with mixed vegetation. Erosion was apparent in some localized areas. Pistol Pond, a former recreation pond located on the eastern half of Landfill 2, was drained in 1986. During periods of precipitation, water is retained in a depressed area in the northwest portion of the pond. In 1986 and 1987, the pond in the FAM CAMP area was dredged, and the material was placed on the north-central portion of Landfill 2. Therefore, trench depressions are not evident in this area on current topographic maps.

3.1.2 Surface Drainage

Regional/Tinker AFB. Drainage of Tinker AFB land areas is accomplished by overland flow of runoff to diversion structures and then to area surface streams, which flow intermittently. The northeast portion of the Base is drained primarily by unnamed tributaries of Soldier Creek, which is itself a tributary of Crutcho Creek. The north and west sections of the Base, including the main instrument runway, drain to Crutcho Creek, a tributary of the North Canadian River. Two small unnamed intermittent streams crossing installation boundaries south of the main instrument runway generally do not receive significant quantities of Base runoff due to site grading designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

Site. Most of the surface water on Landfill 2 discharges to a former recreation pond area, Pistol Pond, located on the eastern half of the landfill. The pond was drained in 1986 and retains little water except for a depressed area in the northwest portion of the former pond that fills during periods of precipitation. The pond area drains to Crutcho Creek through a culvert under Landfill Road. The remainder of the surface water runoff ultimately discharged into Crutcho Creek.

3.2 Geology

3.2.1 Regional/Tinker AFB Geology

Tinker AFB is located within the Central Redland Plain Section of the Central Lowland physiographic province, which is tectonically stable. No major fault or fracture zones have been mapped near Tinker AFB. The major lithologic units in the area of the Base are relatively flat-lying and have a regional westward dip of about 0.0076 foot per foot (ft/ft) (Bingham and Moore, 1975).

Geologic formations that underlie Tinker AFB include, from oldest to youngest, the Wellington Formation, Garber Sandstone, and the Hennessey Group; all are Permian in age.

All geologic units immediately underlying Tinker AFB are sedimentary in origin. The Garber Sandstone and Wellington Formation are commonly referred to as the Garber-Wellington Formation due to strong lithologic similarities. These formations are characterized by fine-grained, calcareously-cemented sandstones interbedded with shale. The Hennessey Group consists of the Fairmont Shale and the Kingman Siltstone. It overlies the Garber-Wellington Formation along the eastern portion of Cleveland and Oklahoma counties. Quaternary alluvium is found in many undisturbed streambeds and channels located within the area.

Stratigraphy. Tinker AFB lies atop a sedimentary rock column composed of strata that ranges in age from Cambrian to Permian above a Precambrian igneous basement. Quaternary alluvium and terrace deposits can be found overlying bedrock in and near present-day stream valleys. At Tinker AFB, Quaternary deposits consist of unconsolidated weathered bedrock, fill material, wind-blown sand, and interfingering lenses of sand, silt, clay, and gravel of fluvial origin. The terrace deposits are exposed where stream valleys have downcut through older strata and have left them topographically above present-day deposits. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

Subsurface (bedrock) geologic units which outcrop at Tinker AFB and are important to understanding groundwater and contaminant concerns at the Base consist of, in descending order, the Hennessey Group, the Garber Sandstone, and the Wellington Formation (Table 3-1). These bedrock units were deposited during the Permian Age (230 to 280 million years ago) and are typical of redbed deposits formed during that period. They are composed of a conformable sequence of sandstones, siltstones, and shales. Individual beds are lenticular and vary in thickness over short horizontal distances. Because lithologies are similar and because of a lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are often informally lumped together as the Garber-Wellington Formation. Together, they are about 900 feet thick at Tinker AFB. The interconnected, lenticular nature of sandstones within the sequence forms complex pathways for groundwater movement.

The surficial geology of the north section of the Base is dominated by the Garber Sandstone, which outcrops across a board area of Oklahoma County. Generally, the Garber outcrop is covered by a veneer of soil and/or alluvium up to 20 feet thick. To the south, the Garber Sandstone is overlain by outcropping strata of the Hennessey Group, including the Kingman Siltstone and the Fairmont Shale (Bingham and Moore, 1975). Drilling information obtained as a result of geotechnical investigations and monitoring well installation confirms the presence of these units.

Depositional Environment. The Permian-age strata presently exposed at the surface in central Oklahoma were deposited along a low-lying north-south oriented coastline. Land features included meandering to braided sediment-loaded streams that flowed generally westward from highlands to the east (ancestral Ozarks). Sand dunes were common, as were cut-off stream segments that rapidly evaporated. The climate was arid and vegetation sparse. Off shore the sea was shallow and deepened gradually to the west. The shoreline's position varied over a wide range. Isolated evaporitic basins frequently formed as the shoreline shifted.

Across Oklahoma, this depositional environment resulted in an interfingering collage of fluviatile and wind-blown sands, clays, shallow marine shales, and evaporite deposits. The overloaded streams and evaporitic basins acted as sumps for heavy metals such as iron, chromium, lead, and barium. Oxidation of iron in the arid climate resulted in the reddish color of many of the sediments. Erosion and chemical breakdown of granitic rocks from the

Table 3-1

Major Geologic Units in the Vicinity of Tinker AFB (Modified from Wood and Burton, 1968)

(Page 1 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	PLEISTOCENE AND RECENT	Alluvium	0-70	Unconsolidated and interfingering lenses of sand, silt, clay, and gravel in the flood plains and channels of stream	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines.
		Terrace deposits	0-100	Unconsolidated and interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above the flood plains of the principal streams.	Moderately permeable. Locally above the water table and not saturated. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

Table 3-1

(Page 2 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
PERMIAN	LOWER PERMIAN	Hennessey Group (includes Kingman Siltstone and Fairmont Shale)	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places water contains large amounts of sulfate.
		Garber Sandstone	500±	Deep-red clay to reddish-orange, massive and cross-bedded fine-grained sandstone interbedded and interfingered with red shale and siltstone	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

KN/1256/SWMU4/SWMU4.3-1/04-07-94/D4 7:39pm

highlands resulted in extensive clay deposits. Evaporite minerals such as anhydrite ($CaSO_4$), barite ($BaSO_4$), and gypsum ($CaSO_4 \bullet 2H_2O$) are common.

Around Tinker AFB, the Hennessey Group represents deposition in a tidal flat environment cut by shallow, narrow channels. The Hennessey Group is comprised predominantly of red shales which contain thin beds of sandstone (less than 10 feet thick) and siltstone. In outcrop, "mudball" conglomerates, burrow surfaces, and dessication cracks are recognized. These units outcrop over roughly the southern half of the Base, thickening to approximately 70 feet in the southwest from their erosional edge (zero thickness) across the central part of Tinker AFB.

In contrast, the Garber Sandstone and the Wellington Formation around Tinker AFB consist of an irregularly-interbedded system of lenticular sandstones, siltstones, and shales deposited either in meandering streams in the upper reaches of a delta or in a braided stream environment. Outcrop units north of Tinker AFB exhibit many small to medium channels with cut and fill geometries consistent with a stream setting. Sandstones are typically cross-bedded. Individual beds range in thickness from a few inches to approximately 50 feet and appear massive, but thicker units are often formed from a series of "stacked" thinner beds. Geophysical and lithologic well logs indicate that from 65 to 75 percent of the Garber Sandstone and the Wellington Formation are composed of sandstone at Tinker AFB. The percentage of sandstone in the section decreases to the north, south, and west of the Base. These sandstones are typically fine to very fine grained, friable, and poorly cemented. However, where sandstone is cemented by red muds or by secondary carbonate or iron cements, local thin "hard" intervals exist along disconformities at the base of sandstone beds. Shales are described as ranging from clayey to sandy, are generally discontinuous, and range in thickness from a few inches to approximately 40 feet.

Stratigraphic Correlation. Correlation of geologic units is difficult due to the discontinuous nature of the sandstone and shale beds. However, cross-sections (Figure 3-1) demonstrate that two stratigraphic intervals can be correlated over large sections of the Base in the conceptual model. These intervals are represented on geologic cross-sections A-A' and B-B' (Figures 3-2 and 3-3). Section A-A' is roughly a dip section and B-B' is approximately a strike section. The first correlatable interval is marked by the base of the Hennessey Group and the first sandstone at the top of the Garber Sandstone. This interval is mappable over the southern half of Tinker AFB. The second interval consists of a shale zone within the Garber Sandstone which, in places, is comprised of a single shale layer and, in other places, of multiple shale layers. This interval is more continuous than other shale intervals and in cross-

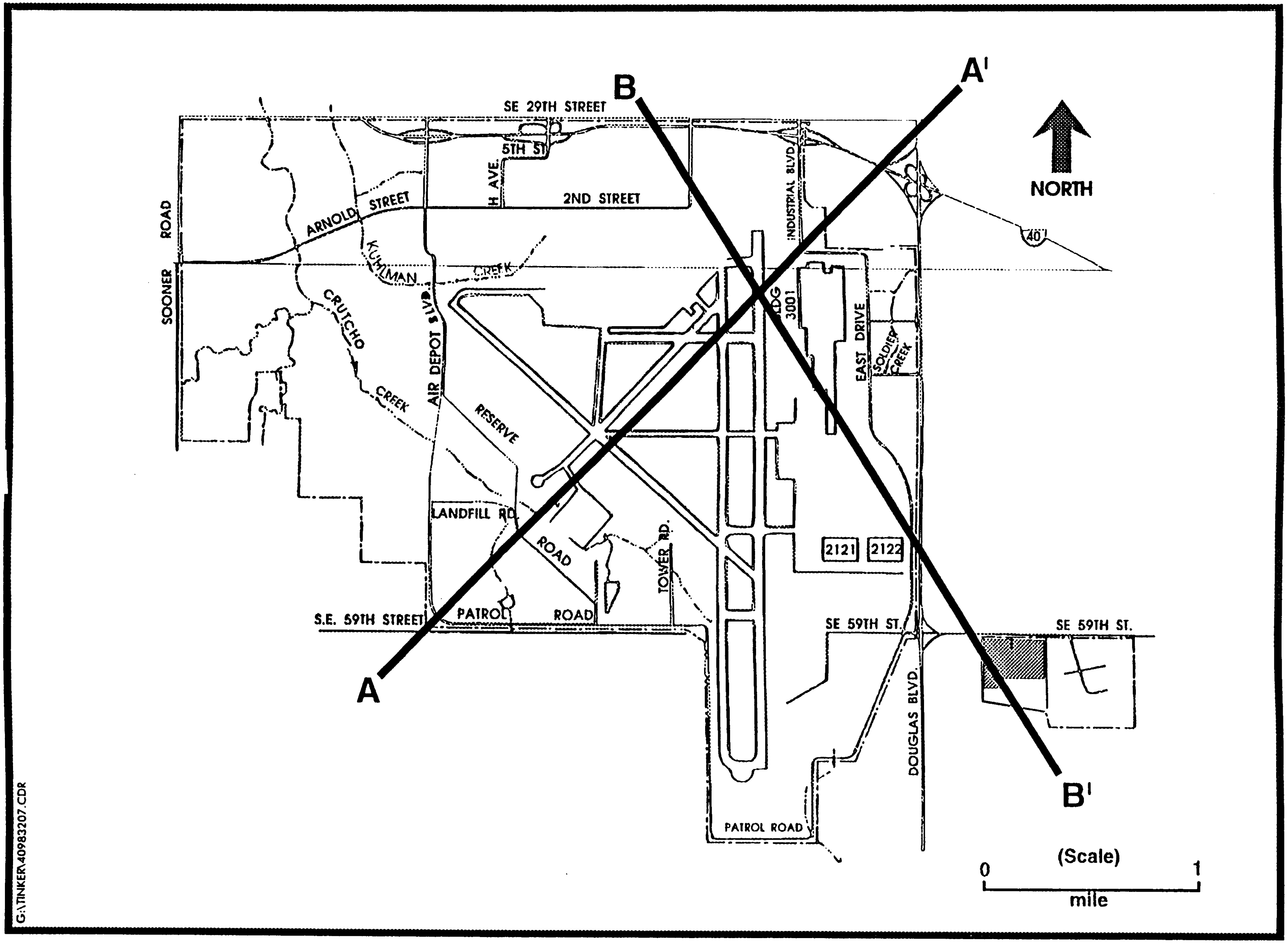


FIGURE 3-1 TINKER AFB GEOLOGIC CROSS SECTION LOCATION MAP

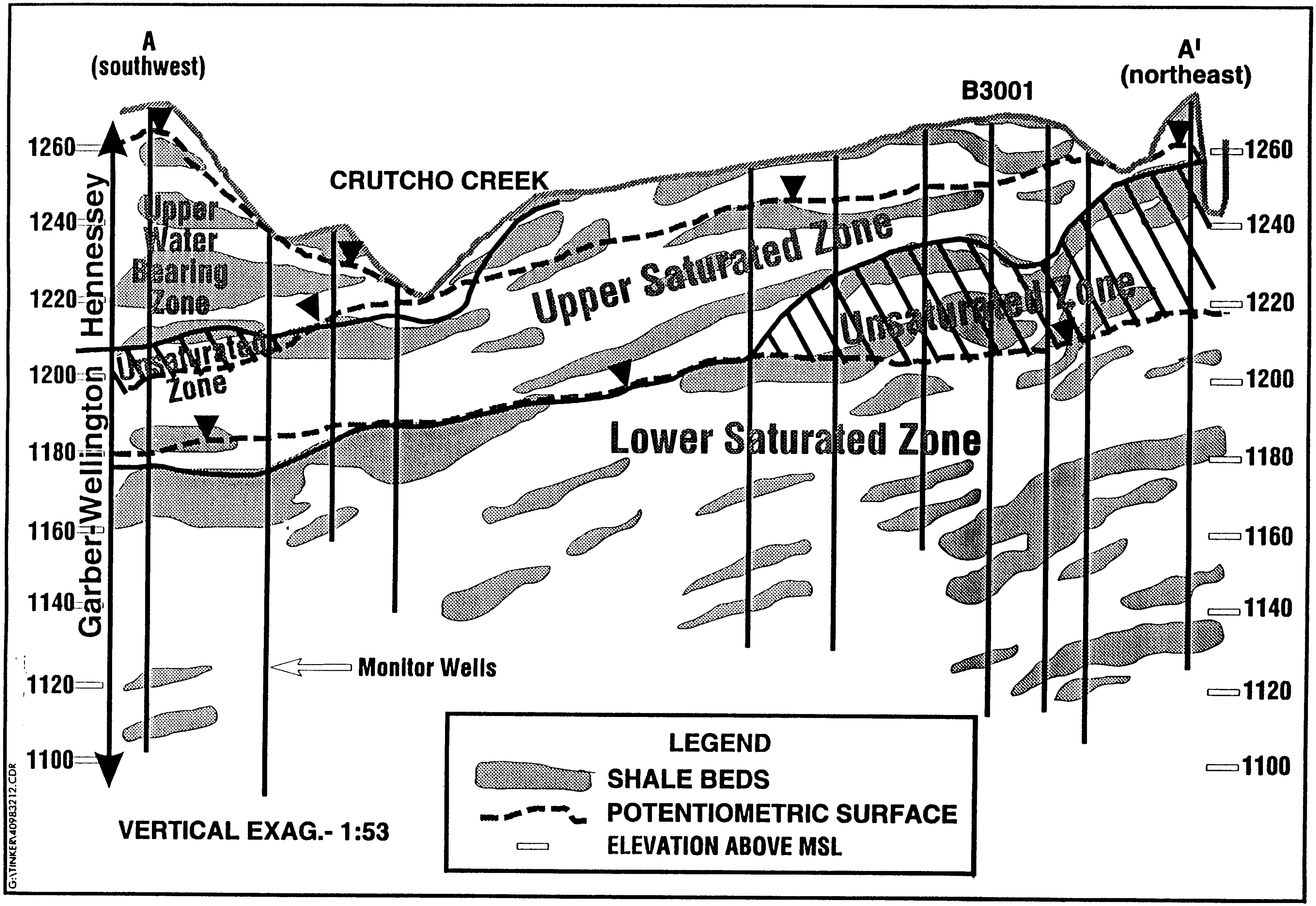


FIGURE 3-2 TINKER AFB GEOLOGIC CROSS SECTION A-A'

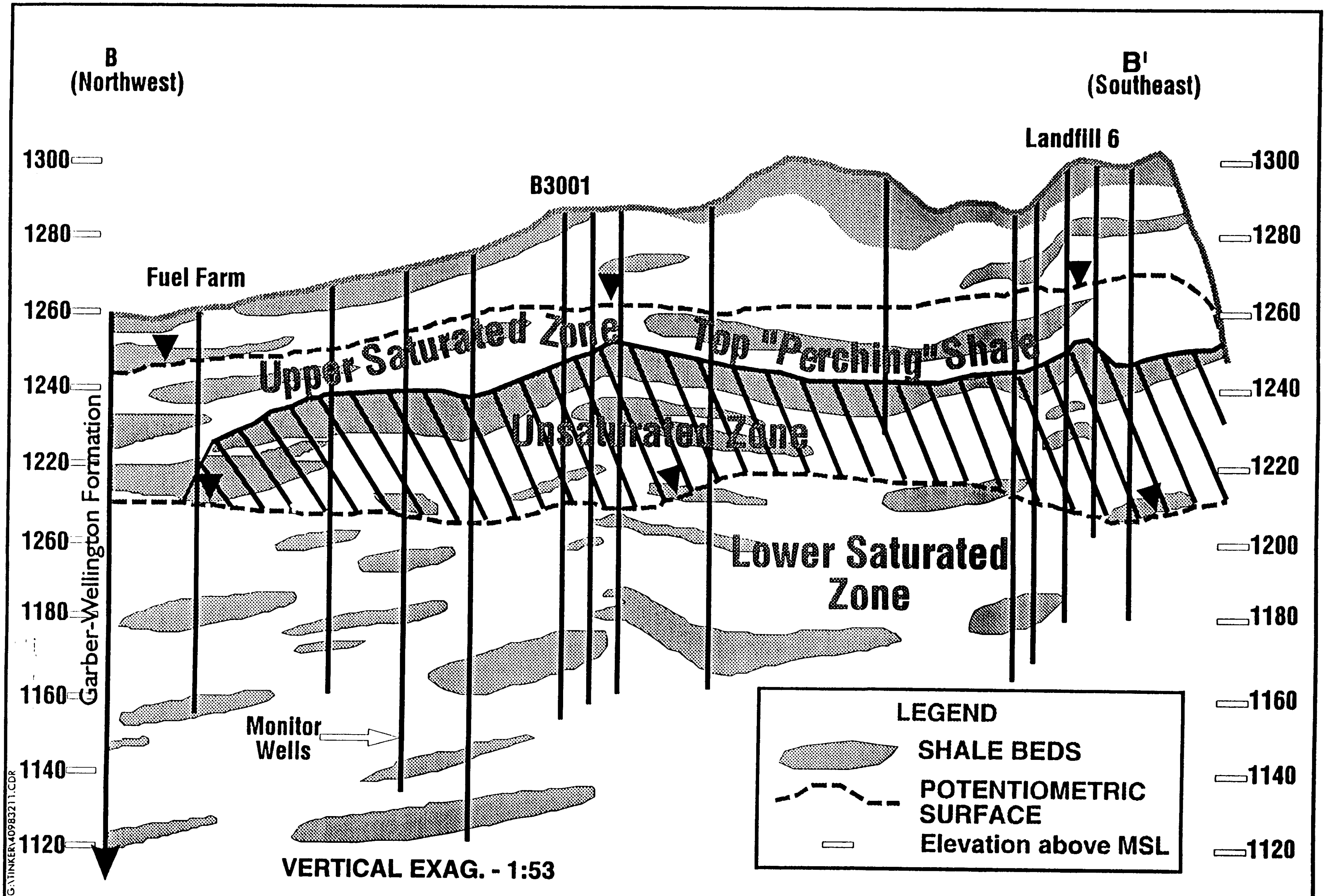


FIGURE 3-3 TINKER AFB GEOLOGIC CROSS SECTION B-B'

sections appears mappable over a large part of the Base. It is extrapolated under the central portion of Tinker AFB where little well controls exists.

Structure. Tinker AFB lies within a tectonically stable area; no major near-surface faults or fracture zones have been mapped near the Base. Most of the consolidated rock units of the Oklahoma City area dip westward at a low angle. A regional dip of 0.0057 to 0.0076 ft/ft in a generally westward direction is supported by stratigraphic correlation on geologic cross-sections at Tinker AFB. Bedrock units strike slightly west of north.

Although Tinker AFB lies in a tectonically stable area, regional dips are interrupted by buried structural features located west of the Base. A published east-to-west generalized geologic cross-section, which includes Tinker AFB, supports the existence of a northwest-trending structural trough or syncline located near the western margin of the base. The syncline is mapped adjacent to and just east of a faulted anticlinal structure located beneath the Oklahoma City Oil Field. The fault does not appear to offset Permian-age strata. There are indications that the syncline may act as a "sink" for some regional groundwater (southwest flow) at Tinker AFB before it continues to more distant discharge points.

3.2.2 Site Geology

Landfill 2 is located within the Hennessey Group, south of the contact between the Hennessey and the Garber-Wellington Formation. The Hennessey Formation outcrops over the southern half of Tinker AFB. The Hennessey thins to the north and pinches out just north of Landfills 1 through 4. It consists of reddish-brown shale with beds of siltstone and silty sandstone. Alluvial deposits (sands, silts, and clays) of varying thickness exist in the shallow subsurface of the Landfill 2 area, extending from the surface down to a depth ranging from 5 to 15 feet below grade. During the RI (USACE, 1993), wastes were discovered in the trench areas just below the cover material and ranged in thickness from a few feet to 18 feet before shale was encountered.

3.3 Hydrology

3.3.1 Regional/Tinker AFB Hydrology

The most important source of potable groundwater in the Oklahoma City metropolitan area is the Central Oklahoma aquifer system. This aquifer extends under much of central Oklahoma and includes water in the Garber Sandstone and Wellington Formation, the overlying alluvium and terrace deposits, and the underlying Chase, Council Grove, and Admire Groups. The

Garber Sandstone and the Wellington Formation portion of the Central Oklahoma aquifer system is commonly referred to as the "Garber-Wellington aquifer" and is considered to be a single aquifer because these units were deposited under similar conditions and because many of the best producing wells are completed in this zone. On a regional scale, the aquifer is confined above by the less permeable Hennessey Group and below by the Late Pennsylvanian Vanoss Group.

Tinker AFB lies within the limits of the Garber-Wellington Groundwater Basin. Currently, Tinker derives most of its water supply from this aquifer and supplements the supply by purchasing from the Oklahoma City Water Department. The nearby communities of Midwest City and Del City derive water supplies from both surface sources and wells tapping the aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by a municipal distribution system also depend on the Garber-Wellington aquifer. Communities presently depending upon surface supplies (such as Oklahoma City) also maintain a well system drilled into the Garber-Wellington as a standby source of water in the event of drought.

Recharge of the Garber-Wellington aquifer is accomplished principally by percolation of surface waters crossing the area of outcrop and by rainfall infiltration in this same area. Because most of Tinker AFB is located in an aquifer outcrop area, the Base is considered to be situated in a recharge zone.

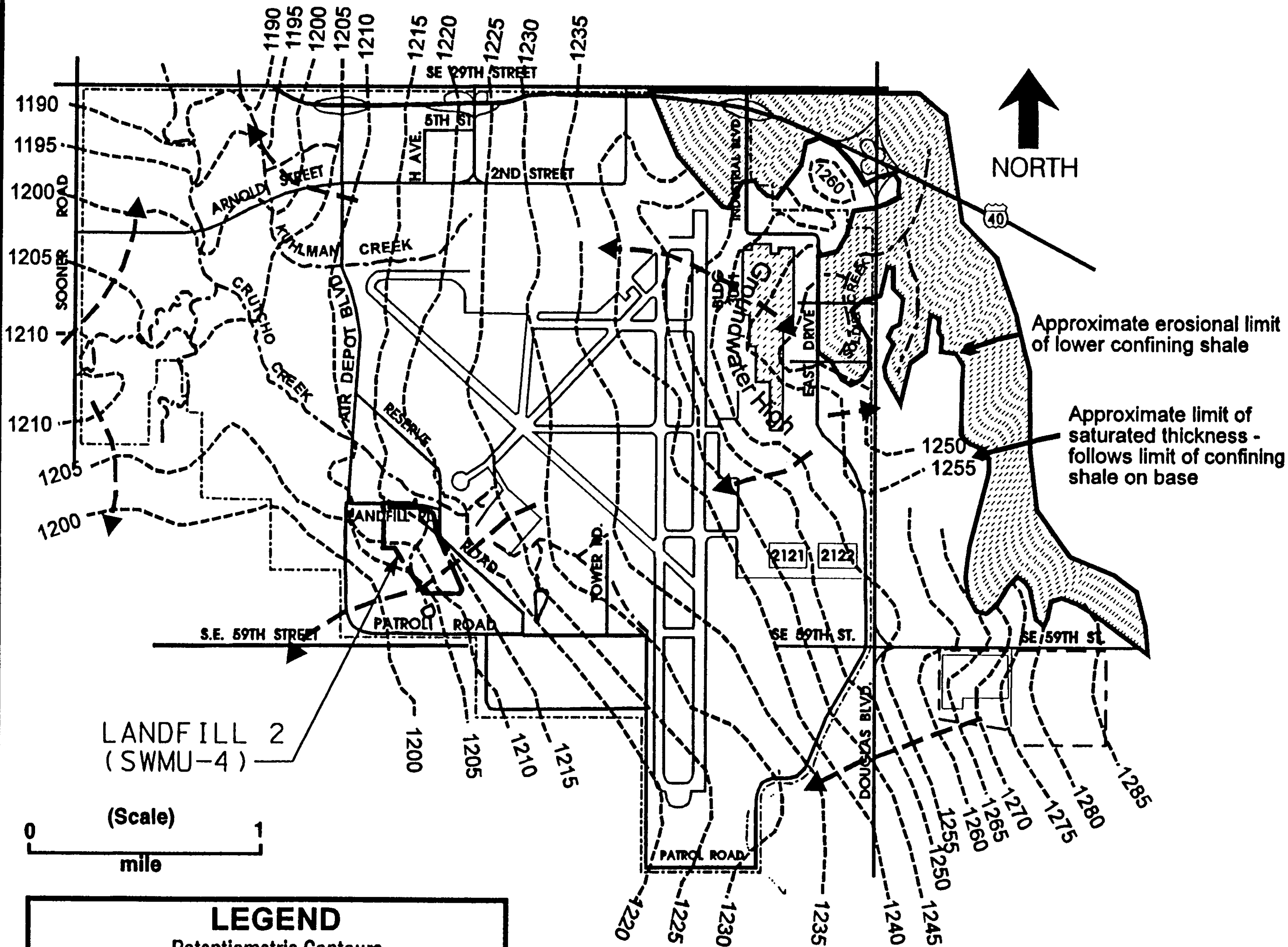
According to Wood and Burton (1968) and Wickersham (1979), the quality of groundwater derived from the Garber-Wellington aquifer is generally good, although wide variations in the concentrations of some constituents are known to occur. Wells drilled to excessive depths may encounter a saline zone, generally greater than 900 feet below ground surface. Wells drilled to such depths or those accidentally encountering the saline zone are either grouted over the lowest screens or may be abandoned.

Tinker AFB presently obtains its water supplies from a distribution system comprised of 29 water wells constructed along the east and west Base boundaries and by purchase from the Oklahoma City Water Department. All Base wells are finished into the Garber-Wellington aquifer. Base wells range from 700 to 900 feet in finished depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones with a combined thickness from 103 to 184 feet (Wickersham, 1979).

Although the variability in the geology and the recharge system at Tinker AFB makes it difficult to predict local flow paths, Central Oklahoma aquifer water table data show that regional groundwater flow under Tinker varies from west-northwest to southwest, depending on location. This theory is supported by contoured potentiometric data from base monitoring wells which show groundwater movement in the upper and lower aquifer zones to generally follow regional dip. Measured normal to potentiometric contours, groundwater flow gradients range from 0.0019 to 0.0057 ft/ft. However, because flow in the near-surface portions of the aquifer at Tinker AFB is strongly influenced by topography, local stream base-levels, complex subsurface geology, and location in a recharge area, both direction and magnitude of groundwater movement is highly variable. The interaction of these factors not only influences regional flow but gives rise to complicated local, often transient, flow patterns at individual sites.

As a result of ongoing environmental investigations and the approximately 450 groundwater monitoring wells installed on the Base during various investigations, a better understanding of the specific hydrological framework has emerged. The current conceptual model developed by Tinker AFB (Tinker, 1993), based on the increased understanding of the hydrological framework, has been revised from an earlier model adopted by the USACE. Previous studies reported that groundwater was divided into four water-bearing zones: the perched aquifer, the top of regional aquifer, the regional aquifer, and the producing zone. In the current model, two principal water table aquifer zones and a third less extensive zone have been identified. The third is limited to the southwest quadrant. The third aquifer zone consisted of saturated siltstone and thin sandstone beds in the Hennessey Shale and equates to the upper water bearing zone (UWBZ) described by the USACE (1993) at Landfills 1 through 4. In addition, numerous shallow, thin saturated beds of siltstone and sandstone exist throughout the Base. These are of limited areal extent and are often perched.

In the current conceptual hydrologic model, an upper saturated zone (USZ) and a lower saturated zone (LSZ) are recognized in the interval from ground surface to approximately 200 feet. Below this is found the producing zone from which the Base draws much of its water supply. Figure 3-4 shows the potentiometric surface for the USZ and Figure 3-5 shows the potentiometric surface for the LSZ. The USZ exists mainly under water table (unconfined) conditions, but may be partially confined locally. Conditions in the LSZ are difficult to determine due to screen placement and overly long sandpacks below the screen interval.



LEGEND

Potentiometric Contours Elevation above MSL

Approximate Direction of Groundwater Flow

Contours are extrapolated across center of base due to lack of data

FIGURE 3-4
TINKER AIR FORCE BASE
UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 23MAR94	DATE LAST REV.:	DRAFT. CHCK. BY:	INITIATOR: C.WALLACE	DWG. NO.:40983209C.
DRAWN BY: C.E.TUMLIN	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J.TAYLOR	PROJ. NO.:409832

G:\TINKER\40983202C.509

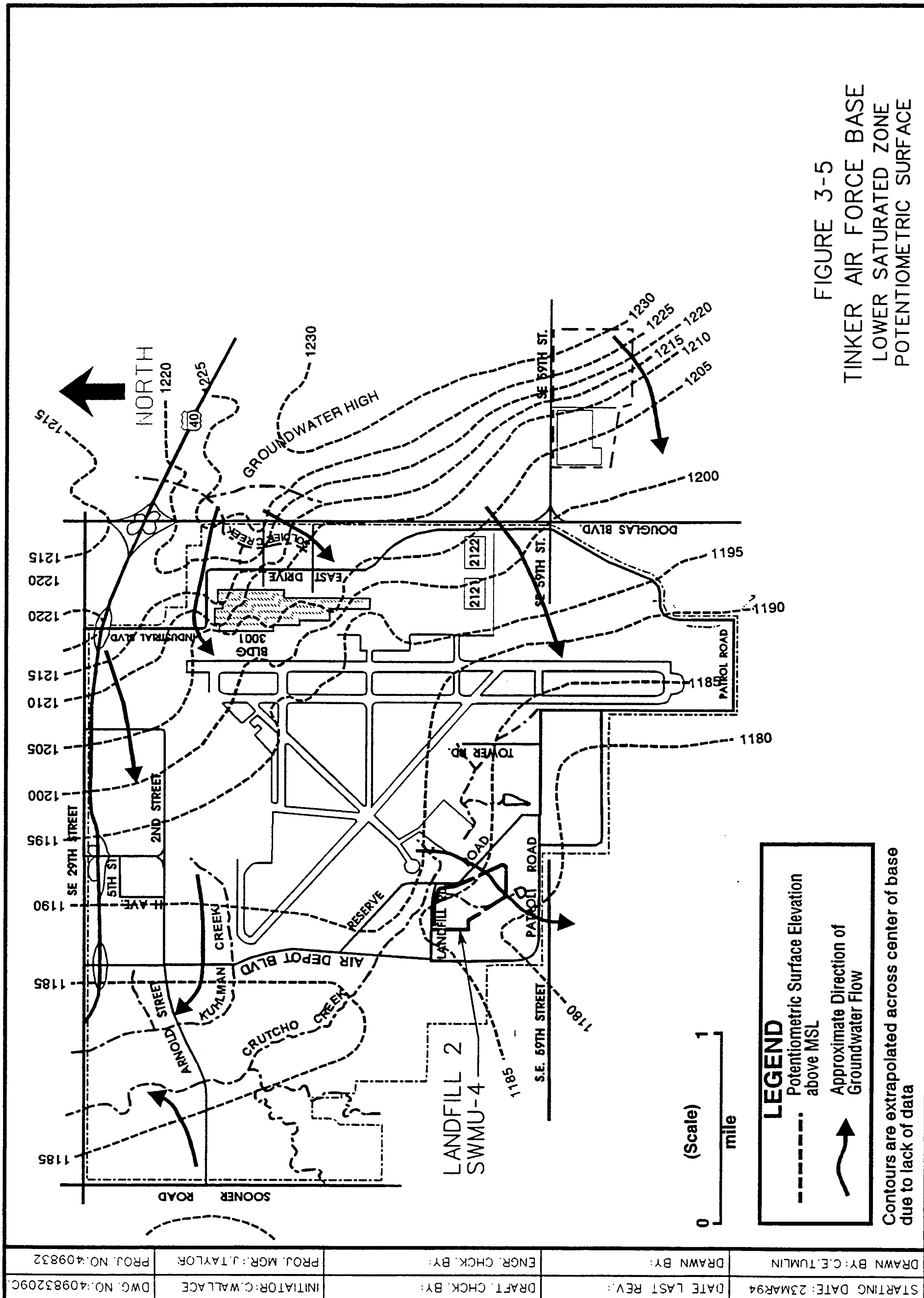


FIGURE 3-5
TINKER AIR FORCE BASE
LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE

The USZ is found at a depth of 5 to 70 feet below ground surface and has a saturated thickness ranging from less than 1 foot at its eastern boundary to over 20 feet in places west of Building 3001. The USZ is erosionally truncated by Soldier Creek along the northeastern margin of Tinker AFB. This aquifer zone is considered to be a perched aquifer over the eastern one-third of Tinker AFB, where it is separated from the LSZ by an underlying confining shale layer and a vadose zone. The confining interval extends across the entire Base, but the vadose zone exists over the eastern one-third of this area. The available hydrogeologic data indicate that the vadose zone does not exist west of a north-south line located approximately 500 to 1,000 feet west of the main runway; consequently, the USZ is not perched west of this line. However, based on potentiometric head data from wells screened above and below the confining shale layer, the USZ remains a discrete aquifer zone distinct from the LSZ even over the western part of the Base. In areas where several shales interfinger to form the lower confining interval rather than a single shale bed, "gaps" may occur. In general, these "gaps" are not holes in the shale, but are places where multiple shales exist that are separated by slightly more permeable strata. Hydrologic data from monitoring wells indicate that these zones allow increased downward flow of groundwater above what normally leaks through the confining layer.

The LSZ is hydraulically interconnected and can be considered one aquifer zone down to approximately 200 feet. This area includes what was referred to by the USACE as the top of regional and regional zones. Hydrogeologic data from wells screened at different depths at the same location within this zone, however, provide evidence that locally a significant vertical (downward) component of groundwater flow exists in conjunction with lateral flow. The magnitude of the vertical component is highly variable over the Base. Preliminary evidence suggests that the LSZ is hydraulically discrete from the producing zone. Due to variations in topography, the top of the lower zone is found at depths ranging from 50 to 100 feet below ground surface under the eastern parts of the Base and as shallow as 30 feet to the west. Differences in potentiometric head values found at successive depths are due to a vertical (downward) component of groundwater flow in addition to lateral flow and the presence or absence of shale layers which locally confine the aquifer system. The LSZ extends east of the Base (east of Soldier Creek) beyond the limits of the USZ where it becomes the first groundwater zone encountered in off-Base wells. Because of the regional dip of bedding, groundwater gradient, and topography, the LSZ just east of the Base is generally encountered at depths less than 20 feet.

3.3.2 Site Hydrology

The groundwater beneath Landfill 2 exists in three distinct zones: the HWBZ, USZ, and LSZ. As stated in Section 3.3.1, the HWBZ is a perched water bearing zone developed in the southwest quadrant of Tinker AFB in the vicinity of Landfills 1 through 4. This zone is characterized by numerous thin saturated siltstone and sandstone beds alternating with shale beds. Delineation of this zone is complicated by a complex stratigraphy of discontinuous water bearing and sealing beds. Due to the complex stratigraphy and limited well control, the HWBZ and USZ are both considered as the USZ for the purposes of this report.

The uppermost saturated zone is the USZ. This zone, which by definition includes the HWBZ, is hydraulically connected to the water encountered in the Landfill 2 trenches and sludge dump. Figure 3-4, which presents the potentiometric surface for the USZ in the Tinker AFB area, shows that groundwater flow in the vicinity of Landfill 2 is generally to the southwest.

Drawings presented in the RI report indicate that the USZ parallels the surface of Landfill 2. Localized areas of leachate discharges were evident across the landfill, especially along the slopes, and have produced areas void of vegetation. Because the USZ parallels ground surface, groundwater recharge in this zone is primarily from surface infiltration. The estimated flow velocity for groundwater through the trenches in the USZ was estimated to be 130 to 160 feet per year. Flow through the material surrounding the trenches was estimated to be approximately 17 feet per year.

The RI report shows that groundwater generally flows to the southwest across the landfill. Vertical migration of the USZ groundwater and contaminants occurs primarily by movement through preferential pathways in the formation under semi-confined and confined conditions, with the interbedded coarser grained material acting as a conduit to the LSZ. The permeability of the USZ formation was measured to be 1.4×10^{-3} cm/s, and that of the underlying siltstone to be 3×10^{-8} cm/s. The estimated flow rate of the USZ is 113 feet per year.

The deepest hydrogeologic zone identified at the site is the LSZ. The LSZ is composed primarily of interbedded shale, siltstone, and sandstone. Figures presented in the RI report (USACE, 1993) depicting potentiometric surfaces for groundwater based on 1987 and 1990 monitoring well data show groundwater flowing in different directions. The 1987 contours show the LSZ flowing to the southeast in the area of Landfill 2; the 1990 contours show the LSZ groundwater flowing to the south/southwest beneath the landfill. However, the overall flow direction is to the southwest as shown in Figure 3-5. The LSZ formation was encountered at depths of 50 to 70 feet below grade and extended to a maximum depth of 125 feet before encountering a lower confining unit. The permeability of the formation was measured to be 1.2 x 10^{-3} cm/s. The estimated flow rate of the LSZ is 48 feet per day.

3.4 Soils

Three major soil types have been mapped in the Tinker AFB area and are described in Table 3-2 (U.S. Department of Agriculture [USDA], 1969). The three soil types, the Darrell-Stephenville, Renfrow-Vernon-Bethany, and Dale-Canadian-Port, consist of sandy to fine sandy loam, silt loam, and clay loam, respectively. The Darrell-Stephenville and the Renfrow-Vernon-Bethany are primarily residual soils derived from the underlying shales of the Hennessey Group. The Dale-Canadian-Port association is predominantly a stream-deposited alluvial soil restricted to stream floodplains. The thickness of the soils ranges from 12 to 60 inches. Landfill 2 lies entirely within the Renfrow-Vernon-Bethany soil association.

Table 3-2

Tinker AFB Soil Associations
(Source: USDA, 1969)

Association	Description	Thickness (in.)	Unified Classification[a]	Permeability (in./hr)
Darrell-Stephenville: loamy soils of wooded uplands	Sandy loam Sandy clay loam Soft sandstone (Garber Sandstone)	12-54	SM,ML,SC	2.0-6.30
Renfrow-Vernon-Bethany: loamy and clayey soils on prairie uplands	Silt loam - clay Clay loam Shale (Fairmont Shale)	12-60	ML,CL,MH,CH	<0.60-0.20
Dale-Canadian-Port: loamy soil on low benches near large streams	Fine sandy loam Silty clay loam Loam Clay loam	12-60	SM,ML,CL	0.05-6.30

[a]Unified classifications defined in U.S. Bureau of Reclamation, 5005-86.

4.0 Source Characterization

Landfill 2 was used primarily for disposal of general refuse generated at the Base, including sanitary and industrial refuse, along with unknown quantities of paints and solvents after the closure of Landfill 1 in 1945. Operations at Landfill 2 ceased in 1952. Boring samples taken at the site revealed the presence of mixed trash primarily consisting of wire, scrap wood and metal, plastic, and paper. One specific-use dump area was located at USACE soil boring location L2-11 in the northeast portion of the landfill. The composite waste sample from boring L2-11 had a black sludge that changed to an asphalt-looking material as the depth increased. There was a strong, rotting smell associated with the sample. Small quantities of low-level radiowaste waste was placed in the trenches of RWDS 1030W, which is located in the central portion of Landfill 2. This site is inactive and remediation efforts began in the spring of 1992. The quantity of waste placed in Landfill 2, other than associated with RWDS 1030W, was estimated to be approximately 603,387 yd^3. The landfill is located in the southwest corner of the Base.

Landfill 2 was constructed by excavating a series of trenches running east-west across the site. The unlined trenches extended to a depth of approximately 20 feet in depth and 35 to 40 feet wide. Refuse was covered daily with several inches of excavated native soil and completed trenches were covered with 3 to 4 feet of soil. The surficial soil of the site is a residual soil of the Renfrow-Vernon-Bethany Association. This soil is the product of in-place weathering of underlying bedrock with a permeability less than 0.06 to 0.20 inches per hour.

The western portion of Landfill 2 is rugged, sloping terrain with mixed vegetation. Erosion is apparent in some localized areas. A former recreational pond, Pistol Pond, located on the eastern half of the landfill, was drained in 1986. Most of the surface water on Landfill 2 discharges to the pond area; however, the pond retains little water except for a depressed area in the northwest portion of the pond that fills during periods of precipitation. The pond area drains to Crutcho Creek through a culvert under Landfill Road. The remainder of the surface water runoff discharges ultimately into Crutcho Creek.

Localized areas of leachate discharges were evident across the landfill, especially along the slopes. These leachate areas have produced areas void of vegetation across the landfill. Rapcon Road intersects the southeast portion of the landfill and provides access to the FAM CAMP Recreational Area. In 1986 and 1987, the pond in the FAM CAMP area was dredged and the material was placed on the north-central area of Landfill 1. Therefore, trench depressions are not evident in this area on current topographic maps. Underground gas, water, sanitary sewer lines, and overhead power lines are located in the southern section of the landfill.

During the course of the remedial investigations conducted by the USACE, 33 IRP soil borings (L2-1 through L2-11-19) were drilled within the landfill trenches. The borings were drilled with an auger to depths that ranged between a minimum of 8 feet at boring L2-11-5 to a maximum depth of 42.4 feet at boring L-2-5. When encountered, samples of the trench waste were collected and composited into one sample for analysis. Upon completion of the boring, the coordinates and ground elevations were surveyed for each boring. In April 1990, 42 soil borings (L4-12A through L4-29C) were drilled along the southwestern edge of Landfill 2 and the southern edge of Landfill 4 to provide definition of the southwest boundary of Landfill 2. The landfill was found to cover approximately 27.5 acres. Table 4-1 contains the waste description and depth of occurrence when waste was encountered for 24 of the 33 trench borings (USACE, 1993). Geologic logs for nine borings (L2-11-2, 3, 4, 7, 13, 14, 15, 16, 17) were omitted. Waste materials were encountered in 14 of the 24 available trench borings.

The nature and extent of soil and groundwater contamination is discussed in detail in Chapter 5.0, Contaminant Characterization.

Table 4-1

Waste
SWMU-4, Landfill 2, Tinker AFB

Boring No.	Waste Description	Depth (feet)
L2-1	Wire, scrap wood, burnt trash	7.0-14.5
L2-2	Wire, scrap wood, burnt trash, scrap metal	7.0-15.5
L2-3	Wire, scrap wood, scrap metal	9.0-15.5
L2-4	Wire, scrap wood, scrap metal, paper, slick moist black material	2.0-15.5
L2-5	Wire, scrap wood, scrap metal, paper, plastic, computer cards	2.0-17.5
L2-6	Wire, scrap wood, paper, plastic	3.0-19.5
L2-7	Wire, scrap wood, scrap metal, paper, plastic, asphalt	2.0-16.0
L2-8	Scrap metal, paper, gravel, asphalt	2.0-13.0
L2-9	No trash encountered	
L2-10	Wire, scrap wood, paper and plastic products	5.5-15.5
L2-11	Rock fragments, wood, charcoal, becomes black near base, moist, no odor	0.0-7.0
L2-11	Disturbed material as above, slight odor which increases with depth, glass fragments	7.0-13.0
L2-11	Black sludge changing to an asphalt-looking material from 14.0 to 17.0 feet, wet, strong rotting smell	13.0-18.0
L2-11-1	Trash (not defined)	5.0-11.5
L2-11-5	No trash or odor reported	
L2-11-6	Sand, gravel, sludge, asphalt	5.5-12.0
L2-11-8	No trash or odor reported	
L2-11-9	Sand, gravel, sludge, asphalt	7.5-12.0
L2-11-10	No trash or odor reported	
L2-11-11	Trash (not defined)	10.0-11.0
L2-11-12	Slight chemical odor	4.0-11.0
L2-11-18	No trash or odor reported	
L2-11-19	No trash or odor reported	
L2-12	No trash or odor reported	
L2-13	No trash or odor reported	
L2-14	No trash or odor reported	

5.0 Contaminant Characterization

Through several phases of investigation, soil and groundwater samples have been collected in and around Landfills 1 through 4 to determine if any environmental contamination has occurred as a result of past waste disposal practices. The investigations have focused primarily on characterizing the materials disposed of within the landfills and on the nature and extent of contaminated soil and groundwater beneath and surrounding the landfills.

A determination of the nature and extent of contaminants migrating specifically from Landfill 2 is complicated by the close proximity of Landfills 1 and 3 to the northeast and Landfill 4 to the west. The determination of "upgradient" or "background" with respect to Landfill 2 concentrations is complicated by multiple potential source areas and complex stratigraphy. Due to the limited number of sampling locations associated with Landfill 2, the contaminant characterization will consist of summarizing the data collected to date and comparing the concentrations of contaminants detected to specific action levels.

Soils. During RI activities performed by the USACE under the IRP (USACE, 1993), 19 samples were reported to have been obtained from 33 soil borings drilled into Landfill 2. The soil samples were collected at various times and were not all analyzed for the same array of chemical constituents. The following analytes were among the parameters tested: VOCs, SVOCs, metals, pesticides, polychlorinated biphenyl (PCB), TPH, total organic carbon (TOC), cyanide, pH, conductivity, gross alpha, gross beta, and radium. A summary of chemical data from the trench soil and the sludge dump samples are provided in Tables 5-1, and 5-2, respectively.

In 1992, ARA was contracted to perform a LIF-CPT study at Tinker AFB. As a part of this study, 11 CPT profiles were performed in Landfill 2 near the sludge dump boring L2-11. During the study, 12 soil samples were collected and analyzed for VOCs, SVOCs, TPH, and metals. Eight of the soil samples were analyzed on site with the remaining four samples submitted to an off-site laboratory for analysis. Tables 5-3 and 5-4 present a summary of the analytical results for these soil samples.

LIF profiling was conducted at seven CPT locations. The LIF became inoperable after the seventh profile and was not used further at Landfill 2. None of the profiles had LIF values above baseline values.

Table 5-1

Summary of Analytical Results, Trench Soil Samples, 1987 Soil Sampling SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 2)

	L2-1	L2-2	L2-3	L2-4	L2-5	L2-6	L2-7	L2-8	L2-10
Volatiles (µg/kg)									
Chlorobenzene	120	460	<10	270	38	17	12	<7	<10
Toluene	330	<10	<10	8J	<7	58	8J	<7	<10
Methylene chloride	<10	200	<10	46	10	26	34	10	<10
Acetone	<10	<10	<10	1500	9J	2700	2600	1700	<10
2-Butanone	<10	<10	<10	22	<14	1600	68	31	<10
Ethyl benzene	<10	<10	<10	8J	<7	34	9	19	<10
Total xylenes	<10	<10	<10	9	<7	95	23	14	<10
2-Hexanone	<10	<10	<10	<15	<14	620	15J	<13	<10
Semivolatiles (µg/kg)									
Di-n-butyl phthalate	160	740	850	230J	<4700	<2600	<5100	<1700	530
Bis(2-ethylhexyl)phthalate	1340	820	1200	5400	3300J	1000J	1400J	<1700	340
Naphthalene	<10	690	550	120J	<4700	160J	870J	<1700	<10
2,4-Dimethylphenol	<25	310	<25	<1000	<4700	<2600	<5100	<1700	<25
Butylbenzyl phthalate	<10	<10	<10	<1000	<4700	<2600	1200J	<1700	300
Metals (mg/kg)									
Silver	5.6	0.64	1.8	1.1	1.0	1.6	0.66	1.0	1.8
Arsenic	2.9	<1.0	<1.0	20	1.0	<1.0	<1.0	1.0	3.6
Barium	330	400	460	2600	510	120	57	160	380
Cadmium	15	5.0	16	6.8	3.1	5.9	1.5	1.3	840

Table 5-1

(Page 2 of 2)

	L2-1	L2-2	L2-3	L2-4	L2-5	L2-6	L2-7	L2-8	L2-10
Metals (mg/kg) (Continued)									
Chromium	110	19	20	25	13	17	9.0	11	17
Mercury	0.46	0.15	0.39	1.4	0.12	0.52	0.18	<0.1	0.46
Nickel	23	12	15	32	9.3	16	13	15	30
Lead	3600	67	190	36	14	21	9.9	9.1	77
Zinc	470	55	240	110	82	99	33	21	2100
Indicators									
TOC (mg/kg)	5700	5000	24,000	12,000	2400	7000	3900	1100	8500
Cyanide (mg/kg)	<0.2	0.2	0.9	1.3	0.27	0.69	<0.2	<0.2	<0.2
pH	7.10	7.27	7.09	6.98	7.18	6.57	7.30	7.48	7.21
Conductivity (μmhos/cm)	900	1100	1100	1400	710	2900	1100	1000	700
Pesticides/PCB(s) (μg/L)									
	None	None	None	None	None	None	None	None	None
Radiometrics (pCi/L)									
	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT

J = The associated numerical value is an estimated quantity.
NRT = Not reported and/or tested.

Note: Laboratory results obtained from Appendix Q of the RI Report (USACE, 1993).

Table 5-2

Summary of Analytical Results, Sludge Dump Samples, 1990 Sampling SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 2)

	L2-11*	L2-11-1	L2-11-5	L2-11-6	L2-11-8	L2-11-9	L2-11-10	L2-11-11	L2-11-12	L2-11-18
Volatile (µg/kg)										
Benzene	<15,000	<5	<5	<5	<5	<5	<5	<5	7	<5
Chloroform	6,000BJ	<5	<5	<5	<5	<5	<5	<5	10.5	<5
Ethyl benzene	<15,000	<5	<5	5.5	<5	<5	<5	<5	<5	<5
Methylene chloride	<15,000	68.2	72.1	13.9	<10	<10	<10	<10	81.1	<10
Toluene	360,000	<5	<5	6.5	<5	11.9	<5	<5	8	<5
Semivolatiles (µg/kg)										
2-Methylphenol	1,700	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT
4-Methylphenol	1,200	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT
Bis(2-ethylhexyl)phthalate	940	<660	700	<3,300	<660	<660	<660	<660	<990	<924
Metals (mg/kg)										
Arsenic	<1.0	0.8	0.9	0.6	0.4	0.6	0.4	0.8	1.1	1.7
Barium	460	342	392	548	132	278	183	265	433	404
Cadmium	7.8	9.57	10.2	50.5	6.31	12.6	5.99	8.42	11.5	49.5
Calcium	NRT	9,970	17,900	13,800	5,330	17,200	16,700	18,900	25,700	25,000
Chromium	91	16.5	20.7	36.7	17.4	19.4	15	21.1	25.1	58.3
Copper	NRT	37.9	11.8	2,890	<10	26	8.86	12.3	41.2	394
Iron	NRT	5,930	5,940	11,700	4,090	5,370	3,320	4,920	7,610	18,000
Lead	67	43.7	15.6	1,500	9.40	54.3	7.78	35.2	55.4	2,090
Magnesium	NRT	7,450	7,040	6,630	6,140	8,250	13,800	2,500	16,800	7,210
Manganese	NRT	563	555	184	230	797	583	278	893	514

KN/1256/SWMU4/SWMU4.5-2/04-06-94/D5 6:40pm

Table 5-2

(Page 2 of 2)

	L2-11*	L2-11-1	L2-11-5	L2-11-6	L2-11-8	L2-11-9	L2-11-10	L2-11-11	L2-11-12	L2-11-18
Metals (mg/kg) (Continued)										
Nickel	67	17.1	19.1	62.5	14.2	15.9	13.5	11.2	25.0	35.7
Potassium	NRT	434	598	156	466	475	367	629	835	1,090
Silver	<0.1	4.76	5.09	14.3	4.58	5.24	4.85	5.57	5.65	15
Sodium	NRT	19.2	<10	198	<10	<10	35.8	571	66.2	74.6
Zinc	270	44.8	21.7	1,480	15.7	134	13.4	26.6	57.2	592
Indicators										
pH (S.U.)	NRT	8.07	8.33	7.66	8.84	8.05	8.51	8.69	8.53	7.82
Conductivity (µmhos/cm)	NRT	290	191	390	141	182	216	430	239	539
TOC (wt%)	NRT	0.44	0.25	9.79	0.25	0.61	0.17	1.29	0.31	2.45
TPH (mg/kg)	NRT	22	19	6,300	NRT	NRT	NRT	NRT	NRT	NRT
Cyanide (mg/kg)	NRT	<1.0	<1.0	4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Pesticides (µg/kg)										
Heptachlor	NRT	NRT	NRT	NRT	<2.0	7.9	<2.0	<2.0	<2.0	<2.0
Radiometrics (pCi/L)										
Gross alpha	NRT	1.7	<0.3	1.4	0.9	0.9	<0.3	2.1	2.7	2.8
Counting error	NRT	1.1	--	0.6	0.8	0.8	--	0.8	0.9	1.0
Gross beta	NRT	6.9	5.6	1.5	5.9	6.6	3.6	9.0	12.2	9.5
Counting error	NRT	1.3	1.2	0.7	1.2	1.2	1.0	1.2	1.3	1.2
Radium	NRT	<0.5	<0.5	1.5	<0.5	1.1	<0.5	1.6	<0.1	<0.1
Counting error	NRT	--	--	0.8	--	0.7	--	0.3	--	--

NRT = Not reported and/or tested.
Note: Laboratory results obtained from Appendix Q of the RI Report (USACE, 1993).
* = Sample collected in 1989.

Table 5-3

On-Site Analysis of Soil Samples
SWMU-4, Landfill 2, Tinker AFB

Location		LF2-07	LF2-07	LF2-05	LF2-05	LF2-06	LF2-06	LF2-10	LF2-10
Depth Interval From	(ft)	8	10	5	7	7.5	9.5	4	6
To	(ft)	9.6	11.6	6.6	8.6	9.1	11.1	5.6	7.6
Methylene chloride		0.045	0.020	0.021	0.024	0.044	<0.020	0.036	0.049
1,1,1-Trichloroethane		<0.020	<0.020	<0.020	<0.020	<0.020	0.056	0.024	0.023

Note: All concentrations are in milligrams per kilogram (mg/kg).

Table 5-4

Off-Site Analysis of Soil Samples SWMU-4, Landfill 2, Tinker AFB

Location	LF2-05	LF2-06	LF2-07	LF2-10
Depth Interval From (ft) To (ft)	5 8.6	7.5 11.1	8 11.6	6 7.6
Date Sampled	10/02/92	10/02/92	10/02/92	10/02/92
Total petroleum hydrocarbon	160	430	370	140
Toluene	<0.005	0.053	NA	<0.005
Total arsenic	11	<1.0	2.6	<1.0
Total barium	790	300	810	1200
Total cadmium	77	13	16	7.7
Total chromium	73	2.2	31	25
Total mercury	0.09	0.09	0.2	<0.001
Total nickel	71	71	34	21
Total lead	1400	580	300	72
Total zinc	1900	1000	280	67

Note: All concentrations in milligrams per kilogram (mg/kg).

Soil Gas. In 1989, Tracer Research Corporation conducted a shallow SGI at Landfill 2. Eight soil gas samples at six locations were collected in the vicinity of boring L2-11. Soil gas samples were collected by driving a 3/4-inch diameter hollow steel pipe fitted with detachable drive points to a depth no deeper than 9 feet into the ground. Sampling locations are presented in Figure 5 of the 1989 SGI report (Tracer, 1989). The analytical equipment was calibrated for the following compounds:

- Benzene
- Toluene
- Ethyl benzene
- Xylenes
- TPH
- 1,1,1-trichloroethane
- Trichloroethene
- Tetrachloroethene.

The analytical results of the SGI are presented in Table 5-5.

In 1990, Tracer performed another shallow SGI at Landfill 2. Samples were collected along grid points on 200-foot centers with the exception of a subsite survey at the sludge dump that was sampled on 50-foot intervals. Sixty-seven soil gas samples were collected in and around the landfill, including 22 samples in the area of the sludge dump. The samples were collected at depths of 1 to 6 feet below grade. Sampling locations are presented in Figures 1 and 2 of the 1990 SGI report (Tracer, 1990). Soil gas samples were analyzed for the following target compounds:

- Trichloroethane
- Trichloroethene
- Tetrachloroethene
- Methane
- Benzene
- Toluene
- Ethyl benzene
- Xylenes
- TPH.

The analytical results of the SGI are presented in Table 5-6.

Table 5-5

Summary of Soil Gas Investigation Results 1989 SWMU-4, Landfill 2, Tinker AFB

Sample	Depth (ft)	Date	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	Total Hydrocarbons (µg/L)
L25G-2	6.5	07/27	0.008	0.008	<0.0002	<0.4	<0.4	<0.04	<0.04	<0.2
L25G-1	7	07/27	0.004	0.001	<0.0002	<0.8	<0.8	<0.4	<0.4	<2
L25G-5	2	07/27	0.0003	<0.0006	<0.0002	<0.04	<0.04	<0.04	<0.04	<0.2
L25G-3	2	07/27	0.0006	<0.0006	<0.0002	<0.04	<0.04	<0.04	<0.04	<0.2
L25G-4	5	07/27	<0.0003	<0.0006	<0.0002	<0.04	<0.04	<0.04	<0.04	<0.2
L25G-4	9	07/27	<0.0003	0.01	<0.0002	12	68	0.5	<0.4	85
L25G-6	9	07/27	0.003	0.007	<0.0002	<0.4	4	<0.4	<0.4	16
L25G-5	9	07/27	0.0006	0.0006	<0.0002	<0.4	<0.4	<0.4	<0.4	<2

Table 5-6

Summary of Soil Gas Investigation Results, 1990
SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 6)

Sample No.	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	THC (µg/L)
03/22/90									
L2/SG-6-5'	0.0006	<0.0002	0.0008	2	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-15-4'	0.0002	0.0005	0.0005	930	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-16-5'	0.0002	0.01	0.02	720	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-25-3'	0.001	<0.0002	0.0006	1	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-14-3'	0.00008	<0.0002	0.0001	890	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-17-5'	0.00008	<0.0002	0.0001	680	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-24-5'	0.0006	<0.0002	0.00005	2	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-13-2'	0.0006	<0.0002	<0.00004	1	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-18-3'	0.0003	<0.0002	0.0002	0.7	<0.02	<0.03	<0.03	<0.03	<0.03
L2/SG-23-4'	0.00008	0.0005	0.0003	700	<0.02	<0.03	<0.03	<0.03	<0.03
AIR	0.0005	<0.0002	<0.00004	2	<0.02	<0.03	<0.03	<0.03	<0.03
03/23/90									
AIR	0.001	<0.0002	0.0004	1	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-22-3'	0.001	<0.0002	0.004	1	<0.02	<0.03	<0.04	<0.04	<0.03

KN/1256/SWMU4/SWMU4.5-6/04-07-94/D6 6:48pm

Table 5-6

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Sample No.	TCA (μg/L)	TCE (μg/L)	PCE (μg/L)	Methane (μg/L)	Benzene (μg/L)	Toluene (μg/L)	Ethyl Benzene (μg/L)	Xylenes (μg/L)	THC (μg/L)
03/23/90 (Continued)									
L2/SG-19-5'	0.0004	<0.0002	0.001	500	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-12-2'	0.002	<0.0002	0.0009	60	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-21-3'	0.0008	<0.0002	0.001	590	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-20-5'	0.0006	<0.0002	0.0007	5200	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-11-5'	0.0009	<0.0002	0.002	30	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-10-4'	0.0002	<0.0002	0.0005	750	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-1-4'	0.001	<0.0002	0.002	1	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-2-5'	0.0003	<0.0002	0.0006	700	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-3-3'	0.0008	<0.0002	0.0004	2400	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-4-2'	0.0008	<0.0002	0.0004	4	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-5-2'	0.002	0.001	0.0006	6	<0.02	<0.03	<0.04	<0.04	<0.03
L2/SG-8-1'	0.0008	<0.0002	0.0002	1	<0.02	<0.03	<0.04	<0.04	<0.03
SG-8-3'	0.0006	<0.0002	0.0002	3	<0.02	<0.03	<0.04	<0.04	0.6
AIR	0.001	<0.0002	0.0005	1	<0.02	<0.03	<0.04	<0.04	<0.03

Table 5-6

(Page 3 of 6)

Sample No.	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	THC (µg/L)
03/24/90									
SG-23-1'	0.002	0.01	0.00009	18000	<0.02	<0.03	<0.03	<0.03	50
SG-32-1'	0.0004	<0.0002	<0.00003	20	0.6	0.8	<0.03	<0.03	2
SG-33-2'	0.0004	<0.0002	0.0002	4	<0.02	<0.03	<0.03	<0.03	<0.03
SG-34-1'	0.0003	0.002	0.00009	400	<0.02	<0.03	<0.03	<0.03	<0.03
SG-39-2'	0.0004	<0.0002	0.0004	2	<0.02	<0.03	<0.03	<0.03	<0.03
SG-38-2'	0.0004	0.001	0.00005	4	<0.02	<0.03	<0.03	<0.03	<0.03
SG-44-2'	0.0004	<0.0002	<0.00003	2	<0.02	<0.03	<0.03	<0.03	<0.03
03/25/90									
SG-66-2'	0.0004	0.001	0.0002	2	<0.03	<0.03	<0.03	<0.03	<0.03
AIR	0.0006	<0.0002	0.0002	2	<0.03	<0.03	<0.03	<0.03	<0.03
SG-67-1'	0.0006	0.0007	0.0004	460	<0.03	<0.03	<0.03	<0.03	<0.03
SG-68-1'	0.0005	<0.0002	0.0003	6	<0.03	<0.03	<0.03	<0.03	<0.03

Table 5-6

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Sample No.	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	THC (µg/L)
03/25/90 (Continued)									
SG-70-1'	0.0006	<0.0002	0.0002	2	<0.03	<0.03	<0.03	<0.03	<0.03
SG-9-2'	0.0007	<0.0002	0.00009	1	<0.03	<0.03	<0.03	<0.03	<0.03
SG-18-2'	0.0004	<0.0002	0.0008	1	<0.03	<0.03	<0.03	<0.03	<0.03
SG-27-1'	0.0004	<0.0002	0.0006	4	0.2	0.03	<0.03	<0.03	0.4
SG-43-7'	0.0003	<0.0002	0.0004	0.6	0.04	<0.03	<0.03	<0.03	0.04
SG-41-1'	0.0002	0.001	<0.00003	3500	<0.03	<0.03	<0.03	<0.03	6
SG-46-6'	0.0001	0.0003	<0.00003	2500	<0.03	<0.03	<0.03	<0.03	10
AIR	0.0003	<0.0002	0.0008	2	<0.03	<0.03	<0.03	<0.03	<0.03
03-26-90									
AIR	0.002	<0.0002	0.002	1	<0.02	<0.03	<0.04	<0.04	<0.03
SG-49-2'	0.0008	<0.0002	0.0008	1	<0.02	<0.03	<0.04	<0.04	<0.03
SG-48-3'	0.0009	<0.0002	0.002	1	<0.02	<0.03	<0.04	<0.04	<0.03
SG-47-2'	0.0007	<0.0002	0.0006	1	<0.02	<0.03	<0.04	<0.04	<0.03
SG-55-5'	0.0008	<0.0002	0.0008	0.7	<0.02	<0.03	<0.04	<0.04	<0.03
SG-36-2'	0.001	<0.0002	0.002	1	<0.02	<0.03	<0.04	<0.04	<0.03

Table 5-6

(Page 5 of 6)

Sample No.	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	THC (µg/L)
03-26-90 (Continued)									
SG-40-3'	0.0004	<0.0002	0.0002	530	<0.02	<0.03	<0.04	<0.04	<0.03
SG-45-2'	0.0003	<0.0002	0.0003	16	<0.02	<0.03	<0.04	<0.04	<0.03
AIR	0.0006	<0.0002	0.0005	1	<0.02	<0.03	<0.04	<0.04	<0.03
03/27/90									
SG-26-6'	0.0004	<0.0002	<0.00003	2	0.05	<0.03	<0.04	<0.04	0.06
SG-6-2'	0.0006	<0.0002	0.0001	16	<0.02	<0.03	<0.04	<0.04	<0.03
SG-5-2'	0.0004	0.004	0.0001	430	4	2	<0.04	<0.04	14
SG-7-2'	0.0006	<0.0002	0.0002	980	<0.02	<0.03	<0.04	<0.04	<0.03
SG-14-2'	0.001	<0.0004	0.0002	18	<0.02	<0.03	<0.04	<0.04	<0.03
SG-15-1'	0.0003	<0.0002	0.0001	1700	<0.02	<0.03	<0.04	<0.04	<0.03
SG-24-1'	0.0005	0.001	0.0004	2900	<0.05	<0.06	<0.07	<0.07	<0.06
03/28/90									
SG-72-3'	0.0009	<0.0002	0.0002	560	<0.02	<0.03	<0.03	<0.03	<0.03
SG-73-1'	0.0006	<0.0002	0.0002	1400	<0.02	<0.03	<0.03	<0.03	<0.03
SG-74-2'	0.001	<0.0002	0.0002	3	<0.02	<0.03	<0.03	<0.03	<0.03

Table 5-6

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Sample No.	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	THC (µg/L)
03/29/90									
SG-85-1'	0.0004	<0.0003	0.0001	4	<0.02	<0.03	<0.03	<0.04	<0.03
SG-86-2'	0.001	<0.0003	0.002	5	<0.02	<0.03	<0.03	<0.04	<0.03
SG-87-1'	0.0004	<0.0003	<0.00005	0.8	<0.02	<0.03	<0.03	<0.04	<0.03
SG-54-2'	0.0005	<0.0003	0.001	0.8	<0.02	<0.03	<0.03	<0.04	<0.03
SG-88-1'	0.0006	<0.0003	0.002	730	<0.02	<0.03	<0.03	<0.04	<0.03
SG-84-3'	0.0004	<0.0003	0.0002	1	<0.02	<0.03	<0.03	<0.04	<0.03

Groundwater. Groundwater in the vicinity of Landfill 2 was investigated by sampling groundwater in soil borings within the landfill and selected groundwater monitoring wells around the perimeter of the landfill. Groundwater from nine trench soil borings and seven sludge dump borings were sampled to characterize the contamination within the USZ in the area of the former landfill trenches and sludge dump. Two samples were obtained from boring L2-3. Tables 5-7 and 5-8 present summaries of the data from the sampling efforts.

During the 1990 LIF-CPT study, ARA collected ten groundwater samples from the USZ for VOC analysis. Five of the samples were analyzed on site and the other five samples were submitted for off-site analysis. Tables 5-9 and 5-10 present summaries of the analytical results for these samples.

Monitoring wells installed around the perimeter of the landfill in the USZ, and the LSZ were sampled to determine the magnitude and extent of contamination. Groundwater samples were collected from nearby wells by the USACE from 1986 to 1990 during the RI, and selected monitoring wells continue to be sampled as a part of the Base groundwater monitoring program. Groundwater samples were submitted for the analysis of the following parameters: VOCs, SVOCs, metals, pesticides, PCBs, indicator parameters, and radiometrics.

Seventeen groundwater monitoring wells are located in close proximity to the landfill as shown in Figure 2-1. Eight wells were selected to evaluate the nature of contamination within the USZ and LSZ. Monitoring wells 5A, 60A, 79B, and 84B are screened across the USZ. Monitoring wells 60B, 79C, 84C, and 4B are screened across the LSZ. The data from monitoring wells screened across multiple zones was not included. Groundwater samples from monitoring wells were submitted for analysis of the same parameters as the water samples collected from the soil borings. Summaries of the 1986 to 1992 groundwater results are presented in Table 5-11 for the USZ and in Table 5-12 for the LSZ.

5.1 Constituents of Potential Concern

The analytical results of soil and groundwater samples from Landfill 2 are available from past IRP investigation activities. Evaluation of these analytical results for the purpose of identifying constituents of potential concern with respect to both human health and the ecological impacts has not been performed. However, an interpretation has been made by comparing analytical results to specific action levels. The action levels for comparison are maximum contaminant levels (MCL), SWMU corrective action levels (CAL), and water quality standards (WQS). The basis for establishing action levels and their definitions is discussed in

Table 5-7

Summary of Analytical Results, Trench Water in the USZ
1987 Water Sampling
SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 3)

	L2-1	L2-2	L2-3	L2-3	L2-4	L2-5	L2-6	L2-7	L2-8	L2-10
Volatiles (µg/L)										
Vinyl chloride	<100	95 J	540	125 J	<100	<100	<100	<200	<50	610
Trans-1,2-dichloroethene	<50	<100	2000	670	<50	<50	<50	<100	<25	3000
Trichloroethene	<50	<100	530	190	<50	<50	<50	<100	<25	380
Acetone	<100	790	<500	370	300	<100	2900	<200	330	<500
2-Butanone	1100	<200	<500	<200	1600	<100	23,000	14,000	260	5600
Ethyl benzene	<50	<100	<250	<100	<50	<50	28 J	<100	64	<250
Total xylenes	<50	<100	<250	<100	<50	<50	<50	<100	26	<250
Chlorobenzene	150	52 J	<250	<100	88	45 J	170	<100	<25	390
2-Hexanone	<100	<200	<500	<200	<100	<100	2700	<200	<50	<500
Toluene	<50	<100	<250	<100	<50	<50	57	<100	<25	<250
Semivolatiles (µg/L)										
1,4-Dichlorobenzene	<100	<50	<10	<20	<50	<50	<100	<100	11	14
2,4-Dimethylphenol	110	78	<10	<20	22 J	<50	77 J	<100	8 J	<10
Benzoic acid	<500	<250	<50	<100	<250	<250	620	<500	13 J	<50
Naphthalene	44 J	19 J	<10	2 J	14 J	<50	37 J	35 J	10	3 J
Metals (µg/L)										
Arsenic	14	22	6.5	5.0	10	8.7	13	14	3.8	6.3
Barium	5000	8500	2600	980	5600	5000	7900	6800	6100	2100
Cadmium	25	110	<7.5	<7.5	60	<7.5	55	190	<7.5	<7.5

Table 5-7

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	L2-1	L2-2	L2-3	L2-3	L2-4	L2-5	L2-6	L2-7	L2-8	L2-10
Metals (µg/L) (Continued)										
Chromium	40	65	<10	93	83	25	85	350	18	<10
Iron	28,000	58,000	NRT	31,000	91,000	1600	120,000	230,000	120,000	2800
Lead	490	820	50	90	290	70	350	1000	60	48
Manganese	2800	1300	NRT	880	1800	2300	750	12,000	500	880
Mercury	0.39	0.46	<0.1	<0.1	0.79	<0.1	0.61	2.0	<0.1	<0.1
Nickel	78	100	20	40	100	90	300	370	68	<10
Silver	<10	<10	<10	<10	18	<10	13	53	<10	<10
Zinc	3000	750	30	58	1400	38	1500	2300	98	65
Indicators (mg/L)										
TOC (mg/L)	36	59	62	29	200	66	1700	210	34	27
Oil and grease (mg/L)	7.0	6.2	NRT	3.0	3.0	2.6	45	2.4	1.2	<1.0
Chloride (mg/L)	100	190	NRT	170	590	450	650	170	50	100
Sulfate (mg/L)	20	20	NRT	52	150	3.0	230	170	49	6.0
pH (s.u.)	6.52	6.16	6.82	6.85	6.35	6.48	6.58	6.55	6.45	6.98
Conductivity (µmhos/cm)	2320	2150	1.89	2040	4160	3050	5870	2080	1730	1679
Pesticides (µg/L)										
	None	None	NRT	None	None	None	None	None	None	None
Radiometrics (pCi/L)										
Gross alpha	109	20	11	NA	19	12	<2	<2	<2	NRT
Counting error	50	15	7	NA	18	10	--	--	--	NRT
Gross beta	187	40	11	NA	68	32	61	34	18	NRT

Table 5-7

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	L2-1	L2-2	L2-3	L2-3	L2-4	L2-5	L2-6	L2-7	L2-8	L2-10
Counting error	33	39	6	NA	58	26	9	13	6	NRT
Total Radium	29	4	<1	NA	<1	<1	<1	<1	<1	NRT
Counting error	5	2	--	NA	--	--	--	--	--	NRT

J = The associated numerical value is an estimated quantity.
NA= Data not available.
NRT= Not reported and/or tested for.
Note: Laboratory results obtained from Appendix P of the RI Report (USACE, 1993) unless noted otherwise.

Table 5-8

Summary of Analytical Results, Sludge Dump Water Samples
1990 Sampling
SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 2)

	L-2-11[a,b]	L2-11-1	L2-11-6	L2-11-8	L2-11-9	L2-11-12	L2-11-19
Volatiles (µg/L)							
Acetone	<10	<10	<10	<10	<10	17*	10
Benzene	NRT	<5	3J*	<5	8*	1J*	<5
Ethyl benzene	7	<5	0.8J*	<5	<5	<5	<5
Methylene chloride	NRT	<5	1J*	3J*	1BJ*	<5	13B*
Xylene (total)	46	<5	<5	<5	<5	0.7*	<5
Toluene	19	<5	<5	<5	<5	<5	<5
Semivolatiles (µg/L)							
Bis(2-ethylhexyl)phthalate	16	7J*	18J*	11J*	82*	54*	0.9J*
Naphthalene	110	<10	5J*	<20	<10	13J*	0.7J*
Metals (µg/L)							
Arsenic	9.1	5.6	3.8	4.0	4.7	10.8	9.9
Barium	26,000	1078*	1780	313	2020*	2330*	576
Cadmium	74	32.3*	249*	249*	<10	37.1*	60.4*
Calcium	NRT	30,200	48,300	16,200	17,000	40,900	31,000
Chromium	68	20.5	41.0	10.2	<10	26.1	33.8
Copper	NRT	1110*	784	<10	24.1	110	530
Iron	180,000	16,500*	27,800*	2350*	4970*	17,900*	11,200*
Lead	96	618*	852*	<20	34.1	299*	334*
Magnesium	26,000	20,000	28,900	12,900	11,500	9260	15,200
Manganese	NRT	1060*	2680*	694*	520*	1610*	834*
Nickel	NRT	45.4	93.5	<15	<15	28.2	26.6
Potassium	NRT	1560	2180	612	450	1190	2750
Silver	<5	18,000	<10	<10	<10	<10	<10
Sodium		18,000	24,600	7970	6220	21,900	10,300
Zinc		1030	2030	31.2	58.6	568	641

Table 5-8

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	L-2-11[a,b]	L2-11-1	L2-11-6	L2-11-8	L2-11-9	L2-11-12	L2-11-19
Indicators (mg/L)							
pH (s.u.)		6.84	7.15	6.97	7.00	6.80	7.01
Cyanide		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Conductivity (μmhos/cm)		1663	1855	1259	1333	1799	1420
TDS (mg/L)		1040	1114	704	1080	1148	846
TOC (mg/L)		14.8	15.5	6.42	12.2	21.7	4.33
TPH (mg/L)		<0.5	1.8*	<0.5	2.4*	3.4*	<0.5
PCBs (μg/L)		None	None	None	None	None	None
Radiometrics (pCi/L)							
Gross alpha		22	86	33	137	9	53
Counting error		10	38	14	54	5	25
Gross beta		36	168	92	220	22	117
Counting error		13	30	15	32	7	16
Total radium		17	80	18	11	11	8
Counting error		2	5	2	4	2	1

NRT = Not reported and/or tested.
* Clear copies of laboratory results are not available to verify results or result is barely legible.

[a]September 1989 sample. Laboratory results not available; therefore, not able to confirm. Results obtained from Tables 4-3A, 4-3B, and 4-10 of the RI Report.
[b]Laboratory results for radiometric parameters are not available in Appendix P of RI Report (USACE). Results obtained from Table 4-3B of the RI Report.

Table 5-9

On-Site Analysis of Water Samples
SWMU-4, Landfill 2, Tinker AFB

Location	L2-11	L2-11-6	L2-11-9	L2-11-12	L2-11-8
Depth Below Ground Surface (ft)	11.7	9.7	12.3	NA	10.3
Date Sampled	10/06/92	10/06/92	10/06/92	10/06/92	10/06/92
Benzene	168	<5	<5	<5	<5
Toluene	27	<5	<5	<5	<5

Note: All concentrations in micrograms per liter (μg/L).

Table 5-10

Off-Site Analysis of Water Samples
SWMU-4, Landfill 2, Tinker AFB

Location	LF2-11	LF2-11-6	LF2-11-9	LF2-11-12	LF2-11-8
Depth Below Ground Surface(ft)	11.7	9.7	12.3	NA	10.3
Methylene chloride	<4.0	<4.0	<4.0	<4.0	<4.0
1,1-Dichloroethene	<4.0	<4.0	<4.0	<4.0	<4.0
1,1,1-Trichloroethene	<4.0	<4.0	<4.0	<4.0	<4.0
1,2-Dichloroethane	<4.0	<4.0	<4.0	<4.0	<4.0
Trichloroethylene	<4.0	<4.0	<4.0	<4.0	<4.0

Note: All concentrations in micrograms per liter (μg/L).

Table 5-11

Summary of 1986, 1987, 1988, 1990, and 1992 Analytical Results, Upper Saturated Zone Monitoring Wells, SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 6)

Compound	MW-5A					MW-60A				
	1986[a]	1988	1989	1990	1992	1987[b]	1988	1989	1990	1992
Volatiles (μg/L)										
Trichloroethene	<5	2 J	<5	<5	2	<5	<5	<5	1 J*	<0.5
Trans-1,2-dichloroethene	9	11	NRT	NRT	<0.5	17	NRT	<5	NRT	<0.5
1,2 Dichloroethane	NA	35	22	21	46	NA	<5	<5	<5	<0.5
1,2-Dichloroethene (total)	NA	NRT	4 J	7	NRT	NA	8	NRT	7*	NRT
Chloroform	<5	<5	<5	1 BJ	<0.5	<5	<5	<5	<5	<0.5
Cis-1,2-dichloroethene	NA	NRT	NRT	NRT	4	NA	NRT	NRT	NRT	<0.5
Methylene Chloride	<5	<5	<5	<5	<0.6	<5	<5	<5	<5	0.5 JB
1,1-Dichloroethane	NA	<5	<5	<5	<0.5	NA	<5	<5	<5	<0.5
Tetrachloroethene	NA	<5	<5	<5	<0.5	NA	<5	<5	<5	<0.5
1,1-Dichloroethene	NA	<5	<5	<5	<0.5	NA	<5	<5	<5	<0.5
1,1,1-Trichloroethane	NA	<5	<5	<5	<0.5	NA	<5	<5	<5	<0.5
Acetone	<10	<10	<10	<10	NRT	NA	<10	<10	<10	NRT
Semivolatiles (μg/L)										
Benzoic Acid	NA	48	<50	<100	NRT	NA	<48	<50	<50	NRT
Bis(2-ethylhexyl)phthalate	10 J	4 J	<10	27 B	6 J	<10	<10	<10	<10	<9
Dimethyl phthalate	NA	<10	<10	<20	26	NA	<10	<10	<10	<9
Naphthalene	NA	<10	<10	<20	2 B	NA	<10	<10	<10	2B
Di-n-butyl phthalate	NA	<10	<10	<20	<10	NA	<10	<10	6 JB*	<9

NOTE: Not all data could be verified due to missing or incomplete analytical data (i.e., 1986 data for MW-5A, 1987 data for MW-60A, Radiometrics 1989 data for MW-60A.

Table 5-11

(Page 2 of 6)

Compound	MW-79B				MW-84B		
	1988	1989	1990	1992	1989	1989	1990
Volatiles (µg/L)							
Trichloroethene	51	150	3,800	3,800	160	170	160
Trans-1,2-dichloroethene	NRT	NRT	NRT	<12	NRT	NRT	NRT
1,2-Dichloroethane	<5	<5	<100	37	<5	<5	<5
1,2-Dichloroethene (total)	41	<5	<100	NRT	<5	NRT	<5
Chloroform	63	<5	77 J	<12	<5	<5	<5
Cis-1,2-dichloroethene	NRT	NRT	NRT	16	NRT	NRT	NRT
Methylene Chloride	<5	<5	<100	<12	18	<5	2 J
1,1-Dichloroethane	12	<5	<100	<12	<5	<5	<5
Tetrachloroethene	120	<5	<100	<12	<5	<5	<5
1,1-Dichloroethene	21	<5	<100	<12	<5	<5	<5
1,1,1-Trichloroethane	11	<5	<100	<12	<5	<5	<5
Acetone	<10	<10	650	NRT	<10	<10	<10
Semivolatiles (µg/L)							
Benzoic Acid	<48	<50	<63	NRT	<50	NRT	<50
Bis(2-ethylhexyl)phthalate	<10	<10	<13	NRT	<10	NRT	45 B
Dimethyl phthalate	<10	<10	<13	NRT	<10	NRT	<10
Naphthalene	<10	<10	<13	<12	<10	NRT	<10
Di-n-butyl phthalate	<10	<10	<13	NRT	<10	NRT	<10

Table 5-11

(Page 3 of 6)

Compound	MW-5A					MW-60A				
	1986[a]	1988	1989	1990	1992	1987[b]	1988	1989[c]	1990	1992
Metals (µg/L)										
Arsenic	2	2.6	1.9	<1.0	<2.0	4.5	3.0	1.6	2.0	2.0
Barium	<500	190	140	16.1	126	1,000	290	290	25.3	123
Cadmium	5	<5	<5	<10	<5.0	<7.5	<5	<5	<10	<5
Chromium	110	150	180	18.5	187	40	<5	12	<10	<7
Iron	NRT	NRT	220	49.5	NRT	24,000	NRT	1,100	229	NRT
Lead	35	19	<10	<20	<42	30	<10	<10	<20	<42
Manganese	NRT	NRT	53	6.8	NRT	390	NRT	84	5.5	NRT
Mercury	0.22	0.24	<0.1	<0.2	<0.2	<0.1	<0.1	0.31	<0.2	<0.2
Nickel	130	NRT	NRT	NRT	<15	40	NRT	NRT	NRT	<15
Selenium	<0.4	1.3	<0.4	<1.0	<2.0	4.1	<0.4	<0.4	<1.0	<2.0
Zinc	45	NRT	NRT	NRT	NRT	60	NRT	NRT	NRT	NRT
Indicators										
pH	7.12	7.64	6.59	6.77	NRT	7.16	7.04	7.29	7.38	NRT
Chloride (mg/L)	77.5	83	86	80.8	NRT	39	40	39	26.6	NRT
Sulfate (mg/L)	781	56	81	75.4	NRT	56	3	20	19.6	NRT
Oil and grease (mg/L)	<1	NRT	<1	<5	NRT	<1	NRT	13	12	NRT
TOC (mg/L)	3.2	5.3	4.35	1.61	3.0	3.8	2	1.48	<0.5	4.6
Conductivity (µmhos/cm)	1,260	1,210	866	1,148	NRT	977	803	500	730	NRT

Table 5-11

(Page 4 of 6)

Compound	MW-79B				MW-84B		
	1988	1989[c]	1990	1992	1989	1989	1990
Metals (µg/L)							
Arsenic	2	<1	<1	NRT	2	NRT	1.5
Barium	350	370	56.9	NRT	500	NRT	71.8
Cadmium	<5	<5	<10	NRT	<5	NRT	<10
Chromium	<5	6.5	<10	NRT	6	NRT	<10
Iron	NRT	320	362	NRT	740	NRT	118
Lead	<10	<10	<20	NRT	<10	NRT	<20
Manganese	NRT	110	16	NRT	110	NRT	7.3
Mercury	0.2	<0.1	<0.2	NRT	<0.1	NRT	<0.2
Nickel	NRT	NRT	NRT	NRT	NRT	NRT	NRT
Selenium	0.5	<0.4	<1	NRT	<0.4	NRT	<1.0
Zinc	NRT	NRT	NRT	NRT	NRT	NRT	NRT
Indicators							
pH	7.09	7.16	7.18	NRT	8.77	7.07	7.32
Chloride (mg/L)	130	66	23.4	NRT	37	NRT	29.9
Sulfate (mg/L)	18	14	7.44	NRT	10	NRT	9.83
Oil and grease (mg/L)	NRT	9.8	<5	NRT	<0.2	NRT	5.4
TOC (mg/L)	0.6	0.381	<0.5	NRT	1.3	NRT	0.799
Conductivity (µmhos/cm)	1,012	710	990	NRT	630	700	851

Compound	MW-5A					MW-60A				
	1986[a]	1988	1989	1990	1992	1987[b]	1988	1989[c]	1990	1992
Radiometrics (pCi/L)										
Gross alpha	<2	NRT	2.89	4	NRT	NRT	NRT	1.66	2	NRT
Counting error	–	NRT	6.31	2	NRT	NRT	NRT	1.91	1	NRT
Gross beta	<3	NRT	13	<3	NRT	NRT	NRT	4.35	5	NRT
Counting error	–	NRT	6.67	–	NRT	NRT	NRT	3.91	3	NRT
Ra-226 + Ra-228	NRT	NRT	0.11	NRT	NRT	NRT	NRT	NRT	NRT	NRT
Counting error	NRT	NRT	0.09	NRT	NRT	NRT	NRT	NRT	NRT	NRT
Total radium	NRT	NRT	NRT	2	NRT	NRT	NRT	0.13	3	NRT
Counting error	NRT	NRT	NRT	1	NRT	NRT	NRT	0.1	1	NRT

Table 5-11

(Page 6 of 6)

Compound	MW-79B				MW-84B		
	1988	1989[c]	1990	1992	1989	1989	1990
Pesticides (μg/L)							
	NRT	NRT	NRT	NRT	NONE	NRT	NRT
Radiometrics (pCi/L)							
Gross alpha	NRT	0.98	3	NRT	5	NRT	<2
Counting error	NRT	5.76	2	NRT	7	NRT	–
Gross beta	NRT	3.66	8	NRT	NRT	NRT	6
Counting error	NRT	6.29	3	NRT	4	NRT	3
Ra-226 + Ra-228	NRT	NRT	NRT	NRT	0.3	NRT	NRT
Counting error	NRT	NRT	NRT	NRT	0.2	NRT	NRT
Total radium	NRT	0.17	2	NRT	NRT	NRT	2
Counting error	NRT	0.11	1	NRT	NRT	NRT	1

[a]Laboratory results not available for 1986 for monitoring well 5A.
[b]Laboratory results not available for 1987 for monitoring well 60A.
[c]Laboratory results for metals, indicators, pesticides, PCBs, and radiometrics not available for 1989 for monitoring well 60A and 79B. Results obtained from USACE RI (1993).
J = Associated numerical value is an estimated quantity.
B = Compound also found in blank.
NA = Not available.
NRT = Not reported and/or tested.
*Clear copies of laboratory results are not available to verify or result is barely legible.
Note: Laboratory results obtained from Appendix O of the RI Report (USACE, 1993) unless noted otherwise.

Table 5-12

Summary of 1987, 1988, 1989, 1990, and 1992 Analytical Results, Lower Saturated Zone SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 3)

Compound	MW-60B					MW-79C			MW-84C			MW-4B				
	1987[a]	1988	1989	1990	1992	1988	1989	1990	1989	1989	1990	1987	1988	1989	1990	1992
Volatiles (µg/L)																
Trans-1,2-dichloroethene	3J	NRT	NRT	NRT	1	NRT	NRT	NRT	NRT	NRT	NRT	<5	NRT	NRT	<5	<0.5
1,1-Dichloroethene	NA	<5	<5	<5	1	<5	<5	<5*	<5	<5	<5*	<5	<5	<5	<5	<0.5
Benzene	NA	<5	<5	<5	18	<5	<5	<5*	<5	<5	<5*	<5	<5	<5	<5	<0.5
Chlorobenzene	NA	<5	<5	<5	3	<5	<5	<5*	<5	<5	<5*	<5	<5	<5	<5	0.2J
Ethyl benzene	NA	<5	<5	<5	1	<5	<5	<5*	<5	<5	<5*	<5	<5	<5	<5	<0.5
Isopropylbenzene	NA	NRT	NRT	NRT	0.5	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	0.1J
Methylene chloride	NA	<5	<5	<5	2B	<5	8	<5*	8	<5	<5*	<5	<5	<5	<10	0.5JB
Tetrachloroethene	NA	<5	<5	<5	2	<5	<5	<5*	<5	<5	<5*	<5	<5	<5	<5	<0.5
Toluene	NA	<5	<5	<5	0.5B	<5	<5	<5*	<5	<5	<5*	<5	<5	<5	<5	<0.5
Trichloroethene	NA	<5	<5	<5	11	<5	<5	12*	<5	<5	0.9J*	<5	<5	<5	<5	0.7
Cis-1,2-dichloroethene	NA	NRT	NRT	NRT	19	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	<0.5
n-Propylbenzene	NA	NRT	NRT	NRT	0.6	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	<0.5
Acetone	NA	<10	<10	<10	NRT	<10	<10	<10*	30	14	12*	65	<10	<10	NRT	NRT
Chloroform	NA	<5	<5	<5	<0.5	<5	<5	<5*	<5	<5	2BJ*	<5	<5	<5	<5	<0.5

Table 5-12

(Page 2 of 3)

Compound	MW-60B					MW-79C			MW-84C			MW-4B				
	1987[a]	1988	1989[b]	1990	1992	1988	1989	1990	1989	1989	1990	1987	1988	1989	1990	1992
Semivolatiles (µg/L)																
Dimethyl phthalate	NA	<10	<10	16J*	20	<10	<10	<13*	<10	NRT	16*	<10	<10	<10	<10	22
Naphthalene	NA	<10	<10	<20	2B	<10	<10	<13*	<10	NRT	<13*	<10	<10	<10	<10	2B
Bis(2-ethylhexyl)phthalate	<10	<10	<10	10J*	<10	<10	<10	<13*	12	NRT	59*	<10	<10	22	11	<10
Metals (µg/L)																
Arsenic	9.7	2	5.3	13.1	2.6	1	2	1.1	21	NRT	66.5	<1	1	2	2.3	<2
Barium	3600	140	250	34.2	290	490	<470	76.9	330	NRT	1280	1600	940	690	85.8	637
Chromium	40	5.5	9	<10	<7	<5	6	<10	23	NRT	34.4	15	11	<5	<10	<7
Iron	35000	NRT	450	484	NRT	NRT	0.03	1140	160	NRT	7670	370	NRT	120	1790	NRT
Lead	50	<10	<10	<20	<42	<10	<10	<20	<10	NRT	28.9	40	14	<10	<20	<42
Manganese	620	NRT	12	14.2	NRT	NRT	<5	26.5	10	NRT	1430	43	NRT	18	85.4	NRT
Mercury	<0.1	<0.1	0.14	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	NRT	<0.2	<0.1	0.1	<0.1	<0.2	<0.2
Nickel	50	NRT	NRT	NRT	<15	NRT	NRT	NRT	NRT	NRT	NRT	23	NRT	NRT	NRT	<15
Selenium	1	<0.4	<0.4	<1.0	<2	<0.4	<0.4	<1.0	<0.4	NRT	<1.0	<0.4	2	<0.4	<1	<2
Zinc	72	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	NRT	20	NRT	NRT	NRT	NRT

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Compound	MW-60B					MW-79C			MW-84C			MW-4B				
	1987[a]	1988	1989[b]	1990	1992	1988[c]	1989	1990	1989	1989	1990	1987	1988	1989	1990	1992
Indicators																
pH (S.M.)	8.08	10.1	7.67	7.63	NRT	7.18	7.29	7.27	11.45	10.65	11.3	12.47	8.16	9.96	10.18	NRT
Chloride (mg/L)	17	17	18	20.2	NRT	26	18	19	16	NRT	33.1	13	11	33	25.7	NRT
Sulfate (mg/L)	25	24	17	21.4	NRT	8	5	8.03	44	NRT	28.7	14	4	2	3.59	NRT
Oil and grease (mg/L)	<1	NRT	13	14	NRT	NRT	<1	<5	<0.2	NRT	<5	<1	NRT	<0.2	<5	NRT
TOC (mg/L)	2.8	1.3	0.5	<0.5	3.5	0.7	0.6	<0.5	4.6	NRT	2.02	9.4	0.7	1.1	<0.5	<1.0
Conductivity (µmhos/cm)	527	424	350	565	NRT	616	470	673	2660	1640	1506	4250	545	240	294	NRT
Radiometrics (pIC/L)																
Gross alpha	NRT	NRT	1.81	3	NRT	NRT	0	5	2	NRT	11	<2	NRT	2	6	NRT
Counting error	NRT	NRT	3.58	2	NRT	NRT	5	2	5	NRT	10	--	NRT	6	4	NRT
Gross beta	NRT	NRT	3.08	4	NRT	NRT	9	6	NRT	NRT	142	22	NRT	5	21	NRT
Counting error	NRT	NRT	4.59	3	NRT	NRT	5	3	4	NRT	11	4	NRT	0	6	NRT
Ra-226 and Ra-228	NRT	NRT	NRT	NRT	NRT	NRT	0.08	NRT	0.2	NRT	NRT	<1	NRT	0.1	NRT	NRT
Counting error	NRT	NRT	NRT	NRT	NRT	NRT	0.2	NRT	0.2	NRT	NRT	--	NRT	0.1	NRT	NRT
Total radium	NRT	NRT	0.07	3	NRT	NRT	NRT	4	NRT	NRT	49	NRT	NRT	NRT	7	NRT
Counting error	NRT	NRT	0.08	1	NRT	NRT	NRT	1	NRT	NRT	4	NRT	NRT	NRT	2	NRT

[a]No laboratory results available for 1987 for monitoring well 60B. Results obtained from USACE RI (1993).
[b]No laboratory results available for metals, indicators, pesticides, PCBs, and radiometrics.
[c]No laboratory results available for pH, conductivity, pesticides, PCBs, and radiometrics. Results obtained from USACE RI (1993).
NA = Not available.
NRT = Not reported and/or tested.
J = Associated numerical value is an estimated quantity.
B = Compound also found in blank.
* Clear copy of laboratory results are not available to verify or result is barely legible.
NOTE: Where analytical data could not be verified, results from the USACE RI (1993) were used.
NOTE: Laboratory results obtained from Appendix O of the RI Report (USACE, 1993) unless noted otherwise.

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Chapter 7.0. In addition, the analytical results from soil samples for metals have been compared to elemental background concentrations in soils.

For soils data, metals concentrations will be compared to established background concentrations. Those metals detected at levels within the range of background concentrations will be considered as naturally occurring and, therefore, below action levels. Any metals at detected concentrations above background, or for which no background concentration has been established, will be compared to SWMU CALs. All other analytes detected in soils will also be compared to SWMU CALs. For groundwater data, all analytes detected will be compared to MCLs. For those analytes for which no MCL has been established, the analytes will be compared to action levels; if no action levels have been established, WQSs will be used for comparison.

5.2 Soil Characterization

During the RI, the USACE assessed the magnitude and extent of contamination originating from historical landfill disposal practices. Soil borings were advanced into areas of suspected contamination at Landfill 2. The results of the soil investigations are discussed with respect to the analytes detected and background metals concentrations in the following sections.

Establishment of Surficial Soil Background Concentrations. Background soil concentrations for trace metals were determined based on a study performed by the USGS (1991). The study area was confined to approximately four counties in central Oklahoma bounded by 34° 45' and 36° north latitude and 96° 45' and 97° 45' west longitude. Tinker AFB lies at the approximate center of this area. A total of 293 B-horizon soil samples were collected within this area. Soil samples were collected at the top of the B-horizon, which was usually 20 to 30 centimeters below the surface but ranged from 3 centimeters to 50 centimeters below the surface. Results of analyses, along with lower detection limits, are summarized in Table 5-13.

The surficial soil concentrations for trace metals reported by the USGS were used to establish the background ("background") concentration for trace metals at all Tinker AFB study sites. Measured environmental concentrations of trace metals in surficial soils at study sites are represented by the arithmetic upper 95^{th} confidence interval on the mean of a normal distribution. The intent of this approach is to estimate a Reasonable Maximum Exposure case (i.e., well above the average case) that is still within a range possible exposures. If the environmental concentration for a given analyte is below or within the minimum-maximum

Table 5-13

Background Concentrations of Trace Metals in Surface Soils[a] SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Concentration in %			
Aluminum	0.005	0.38	8.9
Cadmium	0.005	0.01	9.4
Iron	0.005	0.18	5.8
Magnesium	0.005	0.02	5.3
Phosphorous	0.005	0.06	0.019
Potassium	0.05	0.1	2.4
Sodium	0.005	0.02	0.99
Titanium	0.005	0.04	0.42
Concentrations in ppm			
Arsenic	0.1	0.6	21
Barium	1	47	6400
Beryllium	1	<1	3
Bismuth	10	<DL[b]	<DL
Cadmium	2	<DL	<DL
Cerium	4	14	110
Chromium	1	5	110
Cobalt	1	<1	27
Copper	1	<1	59
Europium	2	---[c]	---
Gallium	4	<4	23
Gold	8	<DL	<DL
Holmium	4	<DL	<DL
Lanthanum	2	7	51
Lead	4	<4	27
Lithium	2	5	100

Table 5-13

(Page 2 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Manganese	10	24	3400
Molybdenum	2	<DL	<DL
Neodymium	4	6	47
Nickel	2	<2	61
Niobium	4	<4	16
Scandium	2	<2	15
Selenium	0.1	<0.1	1.2
Silver	2	<DL	<DL
Strontium	2	13	300
Tantalum	40	<DL	<DL
Thorium	1	<1.40	15.00
Tin	10	<DL	<DL
Uranium	0.1	0.650	6.400
Vanadium	2	5	220
Ytterbium	1	<1	3
Yttrium	2	3	43
Zinc	2	3	79

[a]All B-horizon soil samples (293) from USGS, 1991.
[b]All concentrations below the lower limits of determination.
[c]Insufficient or no data.

range of background concentrations, that analyte was considered to be naturally occurring and no further concern to this investigation. If an analyte's environmental concentration exceeded background, it was identified as requiring further study.

Establishment of surficial soil background concentrations using the top of the B-horizon is a conservative approach in that it is unlikely to reflect all possible anthropogenic influences. Trace metal inputs from anthropogenic sources other than those related to study site-specific disposal activities or operations will not necessarily to be eliminated using this approach. Therefore, responsibility may be taken for more trace metal impacts than are actually attributable to a given site.

5.2.1 Landfill Trenches

Initially, ten soil borings (L2-1 through L2-10) were advanced into areas of suspected contamination at Landfill 2 from December 1986 to February 1987. Boring L2-9 was described by the USACE in the RI as a dry hole with no visible waste being encountered. Therefore, no samples were collected from this boring. In June 1989, four additional soil borings (L2-11 through L2-14) were installed. Based on the geologic logs, waste was encountered at borings L2-12 through L2-14, however, no soil analytical data was provided in the RI report for these borings. At boring L2-11, which is located in the northeast corner of the landfill, a specific-use sludge dump was located. Table 5-1 presents a summary of the contaminant data from samples collected from borings L2-1 through L2-8, L2-10. Boring L2-11 will be discussed in more detail in Section 5.2.2.

The trench soil samples were analyzed for VOCs, SVOCs, metals, pesticides, indicators, and radiometric parameters. Eight VOCs and five SVOCs were detected at concentrations above their analytical method detection limits. The maximum concentrations of each analyte detected are shown below along with their corresponding action level:

Analyte	Maximum Concentration (μg/kg)	Action Level (μg/kg)
2-Butanone	1,600	NE
2-Hexanone	620	NE
2,4-Dimethylphenol	310	NE
Acetone	2,700	8,000,000
Bis(2-ethylhexyl)phthalate	5,400	50,000
Butylbenzyl phthalate	300	20,000,000
Chlorobenzene	460	2,000,000
Di-n-butyl phthalate	850	8,000,000
Ethyl benzene	34	8,000,000

Analyte	Maximum Concentration (μg/kg)	Action Level (μg/kg)
Methylene chloride	200	90,000
Naphthalene	690	NE
Toluene	330	20,000,000
Xylenes (total)	95	200,000,000

NE = Not established

No organic compounds were detected at concentration exceeding their respective action levels.

Nine metals were detected at concentrations above their analytical method detection limits. Six of the metals were detected at concentrations above the background levels established for metals as shown in Table 5-13. The maximum concentrations for each of the six metals are shown below along with their corresponding action level:

Metal	Maximum Concentration (mg/kg)	Action Level (mg/kg)
Silver	5.6	200
Arsenic	20	80
Cadmium	840	40
Mercury	1.4	20
Lead	3,600	NE
Zinc	470	NE

NE = Not established

Metals detected at concentrations above background were cadmium and silver. Cadmium was the only metal detected at concentrations above its action level.

No pesticides, PCBs, or radiometric parameters were detected.

5.2.2 Sludge Dump

As stated in Section 5.2.1, a specific-use sludge dump was located at boring L2-11. In May 1990, 19 borings (L2-11-1 through L2-11-19) were installed radially from boring L2-11 until a location void of any sludge material contamination was established. Table 5-2 presents the summary contaminant data for borings L2-11, L2-11-1, 5, 6, 8, 9, 10, 11, 12, and 18; analytical results for these borings were presented in the RI report.

The sludge dump samples were analyzed for VOCs, SVOCs, metals, pesticides, indicators, and radiometric parameters. The following is a summary of the analytes detected in all the sludge samples collected, including sample L2-11.

Five VOCs and 3 SVOCs were detected at concentrations above their analytical method detection limits. The maximum concentrations of each analyte detected are shown below along with their corresponding action level:

Analyte	Maximum Concentration (µg/kg)	Action Level (µg/kg)
2-Methylphenol	1,700	NE
4-Methylphenol	1,200	NE
Benzene	7	NE
Bis(2-ethylhexyl)phthalate	940	50,000
Chloroform	6,000BJ	100,000
Ethyl benzene	5.5	8,000,000
Methylene chloride	81.1	90,000
Toluene	360,000	20,000,000

NE = Not established

No organic compounds were detected at concentrations exceeding their respective action levels.

Ten metals were detected at concentrations above their analytical method detection limit. Five of the metals were detected at concentrations above the background levels established for metals as shown in Table 5-13. The maximum concentrations for each of the 5 metals are shown along with their corresponding action level:

Metal	Maximum Concentration (µg/kg)	Action Level (µg/kg)
Calcium	25,700	NE
Copper	2,890	NE
Nickel	67	2,000
Silver	15	200
Zinc	1,480	NE

NE = Not established

No metals were detected at concentrations which exceeded their respective action levels.

Pesticides were detected only in a single sample. Heptachlor was detected at a concentration of 7.9 μg/kg in sample L2-11-9, which is below the action level of 80 μg/kg.

The maximum radiometric readings from the samples for gross alpha, gross beta, and radium were 2.8, 12.2, and 1.6 pCi/L, respectively. No radiometric readings above action levels were measured.

Cyanide was detected in sample L2-11-5 at a concentration of 4 mg/kg, below its action level of 2,000 mg/kg.

During the 1992 LIF-CPT study at the sludge dump area in Landfill 2, 12 soil samples were collected and analyzed for VOCs, SVOCs, TPH, and metals. Tables 5-3 and 5-4 present summaries of the analytical results. Three VOCs were reported (methylene chloride, toluene, and trichloroethane). No SVOCs were reported. Eight metals were analyzed at an off-site laboratory. The analytical results reported the metal concentration as total (i.e., total arsenic). Four samples were analyzed for TPH at an off-site laboratory and each reported detections for TPH.

5.2.3 Soil Gas

Two SGIs were performed at Landfill 2. In 1989, eight soil gas samples were collected at six locations in the vicinity of boring L2-11. The samples were collected to depths no greater than 9 feet below grade. The analytical results of this SGI are presented in Table 5-5. Maps depicting sampling locations, compound concentrations, and isoconcentration contours are present in Figure 6, 7, 8 of the SGI report (Tracer, 1989). Chlorinated solvents were not present in any significant levels but there were significant levels of petroleum hydrocarbons. Benzene, toluene, and TPH above 1 μg/L were detected in the trench close to Reserve Road on the east side of the landfill area.

The benzene plume consisted of a small circle around sampling location L2SG-04 at a depth of 9 feet. The one point plume covered a total area of less than 12 feet. The concentration at L2SG-04 was 12 μg/L with a detection limit close to 0.05 μg/L.

The toluene plume had a closed 10 μg/L inner boundary centering around sampling location L2SG-04 with a concentration of 68 μg/L. An open-ended 1 μg/L contour line surrounded the inner boundary with the mouth of the plume opening to the east. The total contourable area of the toluene plume was contained within 50 feet. The detection limits for toluene were approximately 0.05 µg/L.

The TPH plume contained the highest concentrations detected at both areas. At sampling locations L2SG-04 and L2SG-06, the concentrations at 9 feet were 85 µg/L and 16 µg/L, respectively. These two points formed the center of an open-ended plume unbounded to the east. The detection limits for total hydrocarbons was approximately 0.2 µg/L.

Sixty-seven soil gas samples were collected in and around the landfill during the SGI of 1990. The samples were collected at depths of 1 to 6 feet below grade. The analytical results of this SGI are presented in Table 5-6. Maps depicting sample locations, compound concentrations, and isoconcentration contours are presented in Figures 1 through 20 of the 1990 SGI report (Tracer, 1990). All of the VOCs selected for analysis were detected during the survey except ethyl benzene and xylenes. Methane was detected in the highest levels of any of the selected VOCs and produced the most significant and broad plumes across the landfill. Low levels of the chlorinated solvents and remaining petroleum hydrocarbons were also detected. Two small trichloroethane plumes were detected at sampling locations 16 and 23 with a concentration of 0.01 µg/L each. A small tetrachloroethene and trichloroethene plume were detected at sampling location 16 with a concentration of 0.02 µg/L and 0.01 µg/L, respectively. A majority of the landfill was contained within a 10-µg/L contour line. The highest level of methane was detected at sampling location 23 on the western edge of Landfill 2 and adjacent to Landfill 3. A concentration of 15,000 µg/L was reported at this location.

5.3 Groundwater Characterization

The quality of the groundwater in and around the landfill is discussed in the following sections. Trench water in the area of the landfill trenches was sampled in 1987 during the RI. Groundwater in the area of the sludge dump was sampled in 1989 and 1990 as part of the ongoing RI. Groundwater contamination in the USZ and LSZ in the vicinity of the site was further characterized by sampling monitoring wells adjacent to the landfill. The USACE sampled monitoring wells from 1986 to 1990 during the RI. Selected monitoring wells have been sampled since 1990 as part of the facility groundwater monitoring program.

5.3.1 Landfill Trench Water

The Landfill 2 trenches were constructed within the USZ groundwater. Table 5-7 presents a summary of the analytical data collected during groundwater investigations at the landfill in

1987. The data represents the quality of USZ groundwater in the vicinity of the landfill trenches. Groundwater from boring L2-11 will be discussed in Section 5.3.2.

Ten VOCs and four SVOCs were detected at concentrations above their analytical method detection limits. The maximum concentrations of each analyte detected are shown below along with their corresponding action level:

Analyte	Maximum Concentration (µg/L)	Action Level (µg/L
1,4-Dichlorobenzene	14	75
2-Butanone	23,000	NE
2-Hexanone	2,700	NE
2,4-Dimethylphenol	110	NE
Acetone	2,900	4,000
Benzoic acid	620	NE
Chlorobenzene	390	100
Ethyl benzene	64	700
Naphthalene	10	NE
Toluene	57	1,000
Total xylenes	26	10,000
Trans-1,2-dichloroethene	3,000	100
Trichloroethane	530	5
Vinyl chloride	540	2

NE = Not established

Chlorobenzene, trichloroethane, vinyl chloride, trans-1,2-dichloroethene were the only organic compounds detected at concentrations above their action levels.

Eleven metals were detected at concentrations above their analytical method detection limit. The maximum concentrations detected for each of the metals are shown below along with their corresponding action level:

Metal	Maximum Concentration (µg/L)	Action Level (µg/L)
Arsenic	14	50
Barium	8,500	2,000
Cadmium	190	5
Chromium	350	100
Iron	230,000	NE
Lead	1,000	15
Manganese	12,000	NE
Mercury	2.0	2

Metal	Maximum Concentration (µg/L)	Action Level (µg/L)
Nickel	370	100
Silver	53	NE
Zinc	3,000	NE

NE = Not established

Barium, cadmium, chromium, lead, and nickel were all detected at concentrations exceeding their respective action levels.

The maximum radiometric reading from the samples for gross alpha, gross beta, and total radium were 109, 187, and 29 pCi/L, respectively. Both gross alpha and total radium measurements exceeded action levels.

No cyanide or pesticides were detected in reported landfill trench water; they were either not reported or tested for in the sample from boring L2-3.

5.3.2 Sludge Dump Water

From borings associated with the specific-use sludge dump, seven groundwater samples were collected. As discussed in Section 5.2.1, boring L2-11 located the sludge dump. The summary of the analytical data collected from the additional sludge dump borings L2-11-1, 6, 8, 9, 12 and 19 in 1990 is presented in Table 5-8.

Similar to the trench water samples, the sludge dump water samples were analyzed for VOCs, SVOCs, metals, pesticides, indicator and radiometric parameters. Six VOCs and two SVOCs were detected in the sludge dump water samples at concentrations above their analytical method detection limits. The maximum concentrations of each analyte detected are shown below along with their corresponding action level:

Analyte	Maximum Concentration (µg/L)	Action Level (µg/L)
Acetone	17	4,000
Benzene	8	5
Bis(2-ethylhexyl)phthalate	82	6
Ethyl benzene	7	700
Methylene chloride	13B	5
Naphthalene	110	NE

Analyte	Maximum Concentration (µg/L)	Action Level (µg/L)
Toluene	19	1,000
Total xylenes	46	10,000

NE = Not established

Benzene, methylene chloride, and bis(2-ethylhexyl)phthalate were the only organic compounds detected at concentrations above their respective action levels.

Fifteen metals were detected at concentrations above their analytical method detection limit. The maximum concentrations detected for each of the metals are shown below along with their corresponding action level:

Metal	Maximum Concentration (µg/L)	Action Level (µg/L)
Arsenic	10.8	50
Barium	26,000	2,000
Cadmium	249	5
Calcium	40,900	NE
Chromium	41.0	100
Copper	1,110	NE
Iron	180,000	NE
Lead	852	15
Magnesium	28,900	NE
Manganese	2,680	NE
Nickel	93.5	100
Potassium	2,750	NE
Silver	18,000	NE
Sodium	24,600	NE
Zinc	2,030	NE

NE = Not established

The following metals were detected at concentrations exceeding their respective action levels: barium, cadmium, and lead.

The maximum radiometric readings from the water samples for gross alpha, gross beta, and total radium were 137, 220, and 80 pCi/L, respectively. Both gross alpha and total radium measurements exceeded action levels.

The water from boring L2-11 was the only sample tested for chloride and sulfate parameters. Water samples from the other six borings were tested for TPH. Three detections were reported with a maximum concentration of 3.4 µg/L. No PCBs, pesticides, or cyanide were detected in sludge dump water samples.

Ten groundwater samples were collected from the USZ in the vicinity of the sludge dump during the 1992 LIF-CPT study at Landfill 2. Tables 5-9 and 5-10 present a summary of the analytical results. Benzene and toluene were detected in sample L2-11 at concentrations of 168 and 27 µg/L, respectively. Benzene was the only analyte detected above its action level.

5.3.3 USZ Groundwater

Groundwater samples were collected periodically from monitoring wells 5A, 60A, 79B, and 84B which are completed within the USZ. The wells are located around the perimeter of Landfill 2 as shown on Figure 2-1. Between 1986 and 1992, groundwater samples were collected and submitted for laboratory analysis of VOCs, SVOCs, metals, indicator parameters, pesticides, PCBs, and radiometrics. A summary of the groundwater analytical results is presented in Table 5-11.

Twelve VOCs were detected at concentrations above their analytical method detection limits. The maximum concentrations of each analyte detected are shown below, along with their corresponding action limits:

Analyte	Maximum Concentration (µg/L)	Action Level (µg/L)
1,1-Dichloroethane	12	NE
1,1-Dichloroethene	21	7
1,1,1-Trichloroethane	11	200
1,2-Dichloroethane	46	5
1,2-Dichloroethene (total)	41	NE
Acetone	650	4,000
Chloroform	63	100
Cis-1,2-dichloroethene	16	70
Methylene chloride	18	5
Tetrachloroethene	120	5
Trans-1,2-dichloroethane	17	100
Trichloroethane	3,800	5

NE = Not established

Trichloroethane, 1,2-dichloroethane, methylene chloride, tetrachloroethene, and 1,1-dichloroethene were detected at concentrations exceeding their respective action levels.

Five SVOCs were detected at concentrations above their analytical method detection limits. The maximum concentrations of each analyte detected are shown below along with their corresponding action level:

Analyte	Maximum Concentration (µg/L)	Action Level (µg/L)
Benzoic acid	48	NE
Bis(2-ethylhexyl)phthalate	27B	6
Dimethyl phthalate	26	NE
Naphthalene	2B	NE
Di-n-butyl phthalate	6JB	4,000

NE = Not established

Bis(2-ethylhexyl)phthalate was the only SVOC detected above its action limit. The analyte was also detected in a laboratory quality control sample.

Eleven metals were detected USZ monitoring well samples at concentrations above their analytical method detection limits. The maximum concentrations of each meal detected are shown below along with their corresponding action levels:

Metal	Maximum Concentration (µg/L)	Action Level (µg/L)
Arsenic	4.5	50
Barium	1,000	2,000
Cadmium	5	5
Chromium	187	100
Iron	24,000	NE
Lead	35	15
Manganese	390	NE
Mercury	0.22	2
Nickel	130	100
Selenium	4.1	50
Zinc	60	NE

NE = Not established

Chromium, lead, and nickel were the only metals detected at concentrations exceeding their respective action levels.

The maximum radiometric readings from the water samples for gross alpha, gross beta, Ra-226 and Ra-228, and total radium were 5, 13, 0.3, and 3 pCi/L, respectively. No radiometric readings exceeding action levels were measured.

No pesticides, PCBs, or cyanide were detected in the USZ monitoring well samples.

5.3.4 LSZ Groundwater

Groundwater samples were collected periodically from monitoring wells 60B, 79C, 84C, and 4B which are completed within the LSZ. The wells are located around the perimeter of Landfill 2 as shown on Figure 2-1. Between 1986 and 1992 groundwater samples were collected and submitted for laboratory analysis of VOCs, SVOCs, metals, indicator parameters, pesticides, PCB s, and radiometrics. A summary of the groundwater analytical results is presented in Table 5-12.

Fourteen VOCs were detected at concentrations above their analytical method detection limits. The maximum concentrations of each analyte detected are shown below along with their corresponding action limits:

Analyte	Maximum Concentration (µg/L)	Action Level (µg/L)
1,1-Dichloroethene	1	7
Acetone	65	4,000
Benzene	18	5
Chlorobenzene	3	100
Chloroform	2BJ	100
Cis-1,2-dichloroethene	19	70
Ethyl benzene	1	700
Isopropylbenzene	0.5	NE
Methylene chloride	8	5
n-Propylbenzene	0.6	NE
Tetrachloroethene	2	5
Toluene	0.5B	1,000
Trans-1,2-dichloroethene	1	100
Trichloroethane	12	5

NE = Not established

Benzene, methylene chloride, and trichloroethane were the only VOCs detected above their respective action levels.

Three SVOCs were detected at concentrations above their analytical method detection limits. Dimethyl phthalate, naphthalene, and bis(2-ethylhexyl)phthalate were detected at maximum concentrations of 22, 2B, and 59 µg/L, respectively. Bis(2-ethylhexyl)phthalate was the only SVOC which was detected at a concentration exceeding its action level, which is 7 µg/L.

Ten metals were detected at concentrations above their analytical method detection limits. The maximum concentration of each metal detected is shown below along with its corresponding action level.

Metal	Maximum Concentration (µg/L)	Action Level (µg/L)
Arsenic	66.5	50
Barium	3,600	2,000
Chromium	40	100
Iron	35,000	NE
Lead	50	15
Manganese	1,430	NE
Mercury	0.14	2
Nickel	50	100
Selenium	2	50
Zinc	72	NE

NE - Not established

Arsenic, barium, and lead were the only metals detected at concentrations exceeding their respective action levels.

The maximum radiometric readings from water samples for gross alpha, gross beta, Ra-226 plus Ra-228, and total radium were 11, 142, 0.2, and 49 pCi/L, respectively. No radiometric readings in excess of action levels were measured.

No pesticides, PCBs, or cyanide were detected in the LSZ monitoring well samples.

5.4 Characterization Summary

Characterization of soil and groundwater with respect to the nature and extent of contaminants migrating specifically from Landfill 2 cannot be performed at this time due to the limited data available. Additional well control is required to establish upgradient versus downgradient groundwater concentrations within both the USZ and LSZ.

Based on the existing data, a preliminary comparison was made of the analytes tested in the soil borings versus the USZ and LSZ wells. Table 5-14 shows a comparison of the maximum analytes detected in soil and groundwater for those analytes tested for each category. The comparison shows that of the 23 VOCs detected, all but ten were detected within the landfill soils or groundwater. In comparison, 12 of the VOCs were detected in the USZ. Nine SVOCs were detected within the soil or groundwater within the landfill, but only five of these compounds were found in the USZ wells around the landfill perimeter. Five SVOCs were detected in the USZ wells, and only three were detected from LSZ wells.

Silver, arsenic, cadmium, mercury, lead, and zinc were detected within the landfill soil at levels above background. Arsenic, cadmium, mercury, lead, and zinc were also detected in groundwater samples from monitoring wells. Indicator parameters including TOC, oil and grease, chloride, and sulfate were detected in groundwater within and around the landfill.

Radiometric measurements for gross alpha, gross beta, and total radium were detected in groundwater within the landfill, as well as in USZ and LSZ perimeter wells. This data suggests that radioactive materials may potentially be leaching from the landfill.

These observations are preliminary only. Additional data and sampling locations will be required to characterize the full nature and extent of contamination within and migrating from Landfill 2.

Table 5-14

Comparison of Maximum Analytes Detected in Trench Soil, Sludge, and Water Samples Versus USZ and LSZ Groundwater Samples SWMU-4, Landfill 2, Tinker AFB

(Page 1 of 3)

Analyte	Trench Soil/Sludge (µg/kg)	Trench/Boring Water (µg/L)	USZ Groundwater (µg/L)	LSZ Groundwater (µg/L)
Volatiles				
1,1-Dichloroethane	ND	ND	12	ND
1,1-Dichloroethene	ND	ND	21	1
1,1,1-Trichloroethane	ND	ND	11	ND
1,2-Dichloroethane	ND	ND	46	ND
1,2-Dichloroethene	ND	ND	41	ND
2-Butanone	1600	23,000	ND	ND
2-Hexanone	620	2700	ND	ND
Acetone	2700	2900	650	65
Benzene	7	8	ND	18
Chlorobenzene	460	390	ND	ND
Chlorobenzene	ND	ND	ND	3
Chloroform	6,000 BJ	ND	63	ND
Cis-1,2-dichloroethene	ND	ND	16	19
Ethyl benzene	34	64	ND	1
Isopropylbenzene	ND	ND	ND	0.5
Methylene Chloride	200	13 B	18	8
n-Proylbenzene	ND	ND	ND	0.6
Tetrachloroethene	ND	ND	120	2
Toluene	360,000	57	ND	0.5 B
Trans-1,2-dichloroethene	ND	3,000	17	1
Trichloroethene	ND	530	3800	12
Vinyl chloride	ND	540	ND	ND
Xylenes (total)	95	46	ND	ND

Table 5-14

Analyte	Trench Soil/Sludge (µg/kg)	Trench/Boring Water (µg/L)	USZ Groundwater (µg/L)	LSZ Groundwater (µg/L)
Semivolatiles	**(µg/kg)**	**(µg/L)**	**(µg/L)**	**(µg/L)**
1,4-Dichlorobenzene	ND	14	ND	ND
2-Methylphenol	1700	ND	ND	ND
2,4-Dimethylphenol	310	110	ND	ND
4-Methylphenol	1200	ND	ND	ND
Benzoic acid	ND	620	48	ND
Bis(2-ethylhexyl)phthalate	5400	82	27 B	59
Butylbenzylphthalate	300	ND	ND	ND
Di-n-butyl phthalate	850	ND	6 JB	ND
Dimethyl phthalate	ND	ND	26	22
Naphthalene	690	110	2 B	2 B
Metals	**(mg/kg)**	**(µg/L)**	**(µg/L)**	**(µg/L)**
Arsenic	20	14	4.5	66.5
Barium	2600	26,000	1,000	3600
Cadmium	840	249	5	ND
Chromium	110	350	187	40
Lead	3600	1,000	35	50
Magnesium	NRT	28,900	NRT	NRT
Manganese	NRT	12,000	390	1430
Mercury	1.4	2.0	0.22	0.14
Nickel	67	370	130	50
Selenium	ND	ND	4.1	2
Silver	15	18,000	ND	ND
Zinc	1480	3,000	60	72
Indicators	**(mg/L)**	**(mg/L)**	**(mg/L)**	**(mg/L)**
Chloride	NRT	650	130	33.1
Cyanide	4	ND	ND	ND

Table 5-14

(Page 3 of 3)

Analyte	Trench Soil/Sludge (µg/kg)	Trench/Boring Water (µg/L)	USZ Groundwater (µg/L)	LSZ Groundwater (µg/L)
Oil and Grease	NRT	45	13	14
Sulfate	NRT	230	781	44
TOC	24,000	1700	5.3	9.4
TPH	6,300	3.4	NRT	NRT
Radiometrics	**(pCi/L)**	**(pCi/L)**	**(pCi/L)**	**(pCi/L)**
Gross beta	12.2	220	13	142
Gross alpha	2.8	137	5	11
Ra-226 + Ra-228	NRT	NRT	0.3	0.2
Radium	1.6	80	3	49

ND - Not detected at the analytical method detection limit.
NRT - Not reported or tested.

6.0 Potential Receptors

A preliminary draft baseline risk assessment report (USACE, 1991) for Landfills 1 through 4 was issued by USACE in February 1991. The purpose of the risk assessment was to quantify the potential health risks to human receptors at the four sites. The risk assessment was prepared in accordance with EPA guidance documents current at the time. An assessment of site risks to ecological receptors was not included in the report.

The risk assessment treated Landfills 1 through 4 as one site. Therefore, the risks associated with Landfill 2 alone cannot be abstracted from the report. The following is a discussion of the potential receptors identified by the preliminary draft baseline risk assessment report.

6.1 Exposure Assessment Results/Human Receptors

An exposure assessment was performed to determine the potential human receptors and to analyze the potential exposure pathways at Landfills 1 through 4. Potentially exposed human populations were limited to industrial workers associated with Base operations for the following reasons:

- No completed exposure pathway exists now or in the foreseeable future which would potentially expose individuals outside the boundaries of Tinker AFB.
- Access to Tinker AFB is restricted to military personnel, civilian employees, and individuals such as retirees who are authorized to use Base facilities.
- Military housing on Tinker AFB is limited and is not in the vicinity of Landfills 1 through 4.

There were no sensitive subpopulations identified within the industrial site workers determined to represent the potentially exposed population at the sites.

The land use at and near the Base is not expected to change because the facilities have decades of useful life remaining and the Base has an important and continuing mission. Conversion of nearby land to residential use is improbable because of noise and safety concerns associated with such land use around an active airport.

The covered waste trenches and the specific-use sludge dump are the source of contamination at Landfill 2. Potential groundwater contamination via migration of landfill leachate was not identified as a significant transport mechanism. It was determined that contamination of useable groundwater was not possible because of the great horizontal and vertical distances to groundwater use points, and the natural geophysical impediments to contaminant movement in the area. All homes in the area around and downgradient of Landfills 1 through 4 are served by municipal water. Therefore, the potential exposure route involving ingestion of contaminated groundwater was determined to be incomplete for current and future scenarios.

The inactive Radiological Waste Disposal Site (RWDS) 1030W is located in the central portion of Landfill 2. The site was reported to be a burial for burned radium dial waste, including rags and solvent solution. The waste was dumped in a pit, then burned, and then covering of soil was placed over the waste. Remediation of RWDS 1030W began in the spring of 1992 and has not been completed at this time. For additional information regarding this site, see the RCRA Facility Investigation Summary Report, SWMU-19, Radioactive Waste Disposal Site 1030W, April 1994 by IT Corporation.

The only complete exposure pathways identified during the exposure assessment are inhalation of contaminated soil particles and inhalation of organic vapors from contaminated soil.

A summary of the exposure pathways evaluated for potential receptors under current and future land use scenarios, and the rationale for inclusion or exclusion in the risk characterization is presented in Table 6-1.

6.2 Ecological Receptors

Tinker AFB lies within a grassland ecosystem, which is typically composed of grasses, forbes, and riparian (i.e., trees, shrubs, and vines associated with water courses) vegetation. This ecosystem has generally experienced fragmentation and disturbances as result of urbanization and industrialization at and near the Base. While no threatened or endangered plant species occur on the Base, the Oklahoma penstemon (*Penstemon oklahomensis*), identified as a rare plant under the Oklahoma Natural Heritage Inventory Program, thrives in several locations on Base. Tinker AFB policy considers rare species as if they were threatened or endangered and provides the same level of protection for these species.

In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base. However, one specie found on the Base, the Texas horned lizard (*Phrynosoma cornutum*), is a

Table 6-1

Summary of Complete Exposure Pathways SWMUs 3-6, Landfills 1-4, Tinker AFB

Potentially Exposed Population	Exposure Route, Medium and Exposure Point	Pathways Selected for Evaluation?	Reason for Selection or Exclusion
Current Land Use			
Residents	Ingestion of groundwater from local wells downgradient.	No	Pathway is incomplete. All water is from municipal systems in areas downgradient from site.
Residents	Inhalation of contaminated particulates.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Inhalation of organic vapors.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Dermal contact with contaminated particulates.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Incidental ingestion of contaminated particles.	No	General public does not have access to facility or site. Pathway is incomplete.
Industrial workers	Inhalation of contaminated particles.	Yes	Workers will be present intermittently in adjacent facilities.
Industrial workers	Inhalation of organic vapors.	Yes	Workers will be present intermittently in adjacent facilities.
Industrial workers	Dermal contact with contaminated particles.	No	Workers will not be present on the site. Pathway is incomplete.
Industrial workers	Incidental ingestion of contaminated particles.	No	Workers will not be present on the site. Pathway is incomplete.
Future Land Use			
It is anticipated that there will be no long-term change in land use because the site is located on a defense installation that has a critical, continuing mission			

Federal Category 2 candidate specie and under review for consideration to be listed as threatened or endangered. Air Force policy (AFR 126-1) considers candidate species as threatened or endangered and provides the same level of protection.

The Oklahoma Department of Wildlife Conservation also lists several species within the state as Species of Special Concern. Information on these species suggests declining populations but information is inadequate to support listing, and additional monitoring of populations is needed to determine the species status. These species also receive protection by Tinker AFB as threatened or endangered species. Of these species, the Swainson's hawk (*Buteo swainsoni*) and the burrowing owl (*Athene cunicularia*) have been sighted on Tinker AFB. The Swainson hawk, a summer visitor and prairie/meadow inhabitant, has been encountered Basewide. The burrowing owl has been known to inhabit the Air Field at the Base.

7.0 Action Levels

An "action level" is defined by EPA in proposed rule 40 CFR 264.521 (55 FR 30798; 7/27/90), "Corrective Action for Solid Waste Management Units (SWMU) at Hazardous Waste Management Facilities," as a health- and environment-based level, determined by EPA to be an indicator for protection of human health and the environment. In the preamble to this proposed rule, the focus of the RFI phase is defined as "characterizing the actual environmental problems at the facilities." As part of this characterization, a comparison of the contaminant concentrations to certain action levels should be made to determine if a significant release of hazardous constituents has occurred. This comparison is then used to determine if further action or corrective measures are required for a SWMU or an AOC. The preamble to the proposed rule states that the concept of action levels was introduced because of the need for "a trigger that will indicate the need for a Corrective Measures Study (CMS) and below which a CMS would not ordinarily be required" (55 FR 30798; 7/27/90). If constituent concentrations exceed certain action levels at a SWMU or an AOC, further action or a CMS may be warranted; if constituent concentrations are below action levels, a finding of no further action may be warranted. This chapter of the report presents the initial analytical data as compared to certain potential action levels.

Action levels are concentrations of contaminants at or below which exposure to humans or the environment should not produce acute or chronic effects.

The action level information is presented in this chapter so that a constituent concentration at a sample location can be compared with its potential action level. Only constituents identified in the analysis are listed in the SWMU-4, Landfill 2 table. Table 7-1 shows the action levels for soil, water, and air as published in federal or state regulations, policies, guidance documents, or proposed rules.

The action levels listed in Table 7-1 are:

- ***SWMU Corrective Action Levels (CAL)*** **-** The first set of action levels provided in the table are those taken from the proposed rule (40 CFR 264.521) and provided as Appendix A to the rule as "Examples of Concentrations Meeting Criteria for Action Levels." These levels are health-risk based and are provided

Table 7-1

Action Levels
SWMU-4, Landfill 2, Tinker AFB

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Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air (μg/m³)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air (μg/m³)	WQS[e] Water (mg/L)
Volatile Organics							
1,1-Dichloroethene	10		0.03	0.007			
1,1,1-Trichloroethane	7000	3.0	1000	0.2			173.1
1,1,2-Trichloroethane	100	0.006	0.6	0.005			
1,2-Dichloroethane	8.0		0.04	0.005			
Acetone	8000	4.0					
Benzene				0.005			0.714
Carbon disulfide	8000	4.0					
Chlorobenzene	2000	0.7	20	0.1			
Chloroform	100	0.006	0.04	0.1			4.708
Cis-1,2-Dichloroethene	8		0.04	0.07			
Dibromochloride							
Ethyl benzene	8000	4.0		0.7			28.72
Methylene chloride	90	0.005	0.3	0.005			
Styrene	20,000	7.0		0.1			
Tetrachloroethene	10	0.0007	1.0	0.005			
Toluene	20,000	10	7000	1.0			301.9
Trans-1,2-dichloroethene	8		0.04	0.1			
Trichloroethene	60			0.005			
Trichlorofluoromethane	20000	10	700				
Vinyl chloride				0.002			
Xylenes (total)	2.0×10^5	70	1000	10.0			

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air (μg/m^3)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air (μg/m^3)	WQS[e] Water (mg/L)
Semivolatile Organics							
1,2-Dichlorobenzene				0.6			
1,3-Dichlorobenzene				0.6			
1,4-Dichlorobenzene				0.075			
Benzo(a)anthracene				0.0001			
Semivolatile Organics (Continued)							
Benzo(a)pyrene				0.0002			
Benzo(b)fluoranthene				0.0002			
Bis(2-ethylhexyl)phthalate	50	0.003		0.006			
Butylbenzyl phthalate	20,000	7.0		0.1			
Chrysene				0.0002			
Di-n-butyl phthalate	8000	4.0					
Diethyl phthalate	60,000	30					
N-nitrosodiphenylamine	100	0.007					
Nitrobenzene	40	0.02	2.0				
Phenol	50,000	20					4.615
Metals							
Arsenic	80		7.0×10^{-5}	0.05	21		0.0014
Barium	4000		0.4	2	6400		
Beryllium	0.2	8.0×10^{-6}	0.0004	0.004			
Cadmium	40		0.0006	0.005			0.0841
Chromium				0.1	110		3.365
Chromium IV	400		9.0×10^{-5}				
Copper				1.3[f]			
Lead				0.015[f]	27	1.5[g]	0.025
Mercury	20			0.002			0.0006
Nickel	2000	0.7		0.1	61		4.583
Selenium				0.05	1.2		

Table 7-1

(Page 3 of 3)

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air ($\mu g/m^3$)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air ($\mu g/m^3$)	WQS[e] Water (mg/L)
Metals (Continued)							
Silver	200						64.62
Zinc					79		
Radiometrics							
Gross Alpha				15 pCi/L			
Radium-226 + 228				20 pCi/L			
Pesticides							
Heptachlor	0.2	8.0×10^{-6}	0.0008	0.0004			

[a]CAL - Corrective Action Levels
[b]MCL - Maximum Contaminant Levels
[c]USGS - United States Geological Survey
[d]NAAQS - National Ambient Air Quality Standards
[e]WQS - Water Quality Standards
[f]Action Level at the Tap
[g]3 Month Average

as specific examples of levels below which corrective action would not be required.

- ***Maximum Contaminant Levels (MCL)*** - These values are provided from 40 CFR Subpart G, Sections 141.60 through 0.63 as promulgated under the Safe Drinking Water Act. These levels are designated for water media only.

- ***USGS Background*** - These values are provided from the USGS report titled "Elemental Composition of Surficial Materials from Central Oklahoma" (USGS, 1991). These values represent the levels of metals which naturally occur in Central Oklahoma soils.

- ***Background*** - These levels are provided where background could be determined. Where available, background concentrations are listed for metals in soil samples taken on site, which were thought to be unaffected by releases from a unit.

- ***National Ambient Air Quality Standards (NAAQS)*** - These standards are published in 40 CFR Part 50 under the Clean Air Act (CAA) and apply to point sources that emit a limited number of constituents to the air. The constituents regulated are nitrogen dioxide, sulphur dioxide, carbon monoxide, lead, ozone, and particulate matter. Currently, it is assumed that none of the SWMUs emit these compounds in regulated quantities and no air samples have been taken which would allow for a valid comparison.

- ***Water Quality Standards (WQS)*** - The WQS are the standards for surface water quality as established by the State of Oklahoma. These standards apply to point source discharges to surface waters and have been listed for those units adjacent to surface water.

8.0 Summary and Conclusions

Landfill 2 occupies approximately 27.5 acres and is located in the southwest corner of Tinker AFB. The landfill is south of Landfill Road and east of Patrol Road. Approximately 603,387 yd^3 of waste materials are estimated to have been deposited in the landfill between 1945 to 1952. The landfill was used primarily for the disposal of general refuse from on the Base, including sanitary and industrial, along with unknown quantities of paints and solvents. The waste was disposed of in trenches approximately 20 feet in depth and 35 to 40 feet wide, in an east-west operation. Based on the geologic logs, the trash found in the landfill was composed primarily of wood, metal, paper, rubber, and plastic materials. The refuse was covered daily with several inches of excavated native soil and completed trenches were covered with 3 to 4 feet of soil. A specific-use sludge dump area was found in the northeast portion of the landfill during investigation. The material in the dump was composed primarily of industrial solvents and petroleum products. The southern end of Landfill 2 was utilized for a redrumming area. Drummed materials, including a solidified polymer and metal shavings, were found in the trenches on the southwestern edge of Landfill 2.

The inactive RWDS 1030W is located in the central portion of Landfill 2. The site was reported to be a burial for burned radium dial waste, including rags and solvent solution. The waste was dumped in a pit, then burned, and then a covering of soil was placed over the waste. Remediation of RWDS 1030W began in the spring of 1992 and has not been completed at this time. For additional information regarding this site, see the RCRA Facility Investigation Summary Report, SWMU-19, Radioactive Waste Disposal Site 1030W, April 1994 by IT Corporation.

8.1 Soils

The USACE conducted a RI of Landfills 1 through 4 from 1986 to 1990. During the investigations at Landfill 2, 33 borings were advanced into the soil at the former trench sites and sludge dump. Nineteen subsurface samples were collected for analysis. In 1992, ARA collected 12 soil samples from 3 borings advanced at CPT push sites in the vicinity of the sludge dump.

Eight VOCs and five SVOCs were detected in landfill trench soils, but none at concentrations exceeding their respective action levels. Nine metals were detected in the soil samples. Only arsenic, cadmium, mercury, lead, silver, and zinc were detected at concentrations above background. Cadmium was the only metal detected at concentrations exceeding action levels.

Five VOCs and three SVOCs were detected in sludge dump soil samples, but none at concentrations exceeding their respective action levels. Ten metals were detected in the samples. Calcium, copper, nickel, silver, and zinc were detected at concentrations above background. No metals were detected at concentrations above action levels. The pesticide heptachlor was detected in a single sample, but at a concentration below its action level. In addition, cyanide was detected in one soil sample at a concentration below its action level.

8.2 Soil Gas

Two SGIs were performed by Tracer at Landfill 2. In 1989, eight soil gas samples were collected at six locations in the vicinity of boring L2-11, which located a specific-use sludge dump. The samples were collected to depths no greater than 9 feet below grade.

Soil gas samples were analyzed for seven VOCs and total hydrocarbons. Concentrations of all the analytes were detected in soil gas with the exception of tetrachloroethene. Three contaminant plumes were located during the investigation. A small benzene plume was detected around one sample location. A toluene plume was contained in a total contourable area of 50 feet. An open-ended total hydrocarbon plume unbounded to the east toward Reserve Road was the third plume detected.

In 1990, Tracer performed another shallow SGI at Landfill 2. Samples were collected along grid points on 200-foot centers with the exception of a subsite survey at the sludge dump that was sampled on 50-foot intervals. Sixty-seven soil gas samples were collected in and around the landfill, including twenty-two samples in the area of the sludge dump. The samples were collected at depths of 1 to 6 feet below grade.

Soil gas samples were analyzed for methane, seven VOCs, and total hydrocarbons. Concentrations of all the analytes were detected in soil gas except ethyl benzene and xylenes. A significant methane plume was detected across the majority of the landfill with the highest concentrations in the area of Tracer's sampling location 23. This sampling location is on the western edge of Landfill 2 and adjacent to Landfill 3. Two small trichloroethane plumes were detected at Tracer sampling locations 16 and 23 with a concentration of 0.01 μg/L each. A small tetrachloroethene and trichloroethene plume were detected at Tracer's sampling location 16 with a concentration of 0.02 μg/L and 0.01 μg/L, respectively.

8.3 Groundwater

The quality of USZ and LSZ groundwater in the vicinity of Landfill 2 was evaluated during the RI. Groundwater samples were collected from the boreholes drilled during the soils investigation, and monitoring wells surrounding the landfill were sampled. Four monitoring wells were screened in the USZ. Four monitoring wells were screened in the LSZ.

The water samples collected from the soil borings in the landfill trenches are representative of the quality of the USZ groundwater in this area of the landfill. The analytical results from groundwater samples collected in the USZ within the landfill were compared to the action levels developed in Chapter 7.0. Ten VOCs and four SVOCs were detected in the water samples collected from trench borings. Trichloroethene, vinyl chloride, trans-1,2-dichloroethene, and chlorobenzene were the only organic compounds detected at concentrations above their action levels. Eleven metals were detected in the samples. Barium, cadmium, chromium, lead, and nickel were all detected at concentrations exceeding their respective action levels. In addition, both gross alpha and total radium measurements exceeded action levels.

Six VOCs and two SVOCs were detected in sludge dump water samples. Benzene, methylene chloride, and bis(2-ethylhexyl)phthalate were the only organic compounds detected at concentrations above action levels. Fifteen metals were detected in the water samples. Barium, cadmium, and lead were the only metals detected at concentrations exceeding action levels. Both gross alpha and total radium measurements exceeded action levels.

Monitoring wells 5A, 60A, 79B, and 84B were sampled to determine the quality of USZ groundwater adjacent to the landfill. These wells were sampled during the RI groundwater investigation and continue to be sampled as part of the ongoing groundwater monitoring program at Tinker AFB. Twelve VOCs were detected at concentrations exceeding their analytical method detection limits. Trichloroethene, 1,2-dichloroethane, methylene chloride, tetrachloroethene, and 1,1-dichloroethene were detected at concentrations above their respective action levels. Five SVOCs were detected in the samples, but only bis(2-ethylhexyl)phthalate was detected above its action level. Eleven metals were detected in the samples. Chromium, lead, and nickel were the only metals detected above their action levels. Water samples were measured for radiometric readings, but none were measured at levels above action levels.

Monitoring wells 60B, 79C, 84C, and 4B are completed within the LSZ. The wells were sampled to investigate the quality of water within the LSZ adjacent to the landfill. Fourteen VOCs were detected to concentrations above their analytical method detection limits. Benzene, methylene chloride, and trichloroethene were the only VOCs detected above their action levels. Three SVOCs were detected, but only bis(2-ethylhexyl)phthalate was detected above its action level. Of the ten metals detected in the water samples, only arsenic, barium, and lead were detected at concentrations exceeding action levels. No radiometric readings in excess of action levels were measured.

A preliminary comparison of the analytes detected in soil, sludge, and groundwater samples within the landfill versus USZ and LSZ wells around the landfill perimeter suggests that some of the analytes in the USZ and LSZ may not have been sourced by Landfill 2.

8.4 Interim Remedial Actions

No interim remedial actions have been completed at Landfill 2, but the design for a 28-acre landfill cap was completed in September 1992 and is not scheduled for installation. The landfill cap will require the rerouting of underground gas, water, sanitary sewer lines, and overhead power lines located in the southern portion of Landfill 2.

9.0 Recommendations

The following paragraphs describe additional work for the Phase II RFI. Additional investigations are required to fully characterize the nature and extent of contamination, and the risks to human health and the environmental at Landfill 2. Based on the location of this site, it will be more appropriate to investigate it as part of a group comprising several waste units in close proximity: RWDS 1030W, RWDS 1022E, RWDS 62598, Landfills 1, 3, and 4, the SP, and FTA1. Details of specific sampling needs will be presented in the work plan/sampling plan for the Phase II RFI.

Review of Landfills 1 through 4 RI Report. Upon comparison of the summary tables of analytical results presented in Volume I of the RI report and the available laboratory results in Volumes 3 and 4, numerous discrepancies were noted. A thorough review should be performed to resolve the discrepancies. The accuracy of these summary tables is crucial to the text of the RI. It was also noted that not all of the laboratory results were present to completely verify results listed in the summary tables.

In the previous investigations, data has been collected to characterize contaminated soils and groundwater within the landfill and investigate groundwater contamination around the perimeter of the landfill. A Phase II field investigation is recommended to perform the following tasks:

- Install additional soil borings to characterize contaminated vadose zone soils within Landfill 2 and to determine the vertical and horizontal extent of contamination.

- Install additional monitoring wells in the HWBZ, USZ, and LSZ to characterize and determine the lateral and vertical extent of groundwater contamination originating from Landfill 2.

- Perform aquifer testing to obtain data to evaluate potential transport and migration of contaminants.

- Perform a baseline risk assessment to assess potential impacts to human health and the environment.

Installation of Additional Soil Borings. The existing analytical data from soil borings should be reviewed in conjunction with the soil gas survey data to select locations for additional soil borings. Boring locations should be chosen to obtain additional data to delineate the lateral and vertical extent of all analytes which were identified at concentrations above action levels. Borings should be drilled using a hollow-stem auger with continuous 5-foot sampling from the ground surface to the top of the water table.

Installation of Additional Groundwater Monitoring Wells. The current well control adjacent to Landfill 2 includes three-well clusters at locations 59, 60, 79, and 84. At each cluster, wells are completed in the HWBZ, USZ, and LSZ water-bearing zones. Additional monitoring wells are needed to:

- Delineate the HWBZ and USZ separately, as opposed to the USZ as currently defined in this report, which includes both zones.
- Determine the direction of localized groundwater flow within the HWBZ, USZ, and LSZ.
- Determine the vertical extent of contamination in the LSZ.
- Delineate the lateral extent of the groundwater plume downgradient from the landfill with respect to analytes detected above action levels.

Installation of a shallow monitoring well completed in the HWBZ is recommended next to existing well pair 4A and 4B. Installation of this well will establish a fifth 3-well cluster completed in the HWBZ, USZ, and LSZ on the north side of Landfill 2. The resulting well configuration should provide adequate well control to determine groundwater flow direction and background versus downgradient contaminant concentrations within all three zones. Once the downgradient direction is established for each zone, an additional well will be installed in each zone downgradient from the landfill and away from its perimeter to establish the lateral extent of groundwater contamination. Every monitoring well will have a 10-foot screen unless geologic conditions require shorter screens. All monitoring wells will be added during the Phase II RFI as part of the basewide groundwater investigation.

Due to the close proximity of Landfills 1 through 4 and other adjacent waste units, attempting to track the migration of specific contaminants at a distance from the perimeter of a single landfill may not be practical. In determining the lateral extent of contaminated groundwater associated with the landfills, it is recommended that the four landfills and the adjacent waste units be considered as a single point source. Using this assumption, monitoring wells will be installed around the perimeter of these waste units to establish the lateral extent of contaminants in groundwater.

All monitoring wells should be sampled and analyzed for VOCs, SVOCs, metals, inorganic parameters, and radionuclides.

Aquifer slug testing should be performed on selected monitoring wells to obtain data to calculate groundwater flow rates. At minimum, slug tests will be performed for one upgradient and one downgradient well for each zone.

After the completion of the Phase II field investigations, a baseline risk assessment should be performed to evaluate potential threats to human health and the environment.

In addition, to fully evaluate the extent of soil contamination at this site it is recommended that site-specific soil background samples be collected during the Phase II RFI. This additional information along with the USGS background values should be used in the Phase II report to distinguish site-related from background concentrations in a statistically significant manner. During the development of the Phase II RFI work plan, the number of background samples to be collected, the location of the soil borings, and the soil analysis to be performed on the samples should be determined for EPA approval.

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Final Report
Phase I RCRA Facility Investigation for Appendix I Sites

VOLUME VII

SWMU-5, Landfill No. 3

Department of the Air Force
Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma

September 1994

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List of Acronyms

AFB	Air Force Base
AOC	area of concern
B&V	B&V Waste Science and Technology Corporation
CAL	Corrective Action Level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CMS	Corrective Measures Study
cm/s	centimeters per second
DCQAP	Data Collection Quality Assurance Plan Amendment
DERP	Defense Environmental Restoration Program
DOD	U.S. Department of Defense
EID	Engineering Installation Division
EP	extraction procedure
EPA	Environmental Protection Agency
ES	Engineering Science
ft/ft	foot per foot
HARM	hazardous assessment rating methodology
HSWA	Hazardous and Solid Waste Amendments
IRP	Installation Restoration Program
JP-4	jet petroleum grade 4
LSZ	lower saturated zone
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level
NPL	National Priorities List
PA/SI	preliminary assessment/site investigation
PCB	polychlorinated biphenyls
pCi/L	picocuries per liter
POL	Petroleum Oil Lubricant (Facility)
ppm	parts per million
PRC	PRC Environmental Management, Inc.

RCRA	Resource Conservation and Recovery Act
RD&D	research development and demonstration
RI/FS	remedial investigation/feasibility study
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TSD	treatment, storage, and disposal (facility)
USACE	U.S. Army Corps of Engineers
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USC	U.S. Code
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USZ	upper saturated zone
UWBZ	upper water bearing zone
VOC	volatile organic compounds
WQS	water quality standard
yd^3	cubic yards

Executive Summary

This report provides a summary of the various investigations that have been conducted at solid waste management unit (SWMU)-5, Landfill No. 3 (Landfill 3), Tinker Air Force Base (AFB), Oklahoma. The report has been prepared to determine and document whether sufficient investigations at Landfill 3 have been performed to meet regulatory requirements. Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County. The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. The Base encompasses approximately 5,000 acres.

Background. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon^{TM}, jet fuels, and radium paints.

In 1984, Congress amended the Resource Conservation and Recovery Act (RCRA) with the Hazardous and Solid Waste Amendments (HSWA), which allow U.S. Environmental Protection Agency (EPA) to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or contaminants from any solid waste management unit (SWMU) at a treatment, storage, and disposal (TSD) facility. On January 12, 1989, Tinker AFB submitted its Part B permit application for renewal of its operating RCRA Hazardous Waste Storage facility permit. The final RCRA HSWA permit issued on July 1, 1991, requires Tinker AFB to investigate all SWMUs and areas of concern (AOC) and to perform corrective action at those identified as posing a threat to human health or the environment. The permit specifies that a RCRA Facility Investigation (RFI) be conducted for 43 identified SWMUs and two AOCs on the Base. This document has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 3.

Source Description. Landfill 3 was used for the disposal of an estimated 180,000 cubic yards (yd^3) of general refuse generated by Tinker AFB from 1952 to 1961. Industrial wastes such as paint buckets, insecticide cans, and barrels were also deposited in the landfill. Two specific-use dump areas are located within the boundaries of Landfill 3.

- A sludge dump, located in the south-central area of the landfill, was in use from 1961 to 1968. This dump is reported to contain waste oils and other liquids from industrial operations at Building 3001 and waste fuels and sludge from the Petroleum Oil Lubricant (POL) Facility (U.S. Army Corps of Engineers [USACE], 1989).

- An area reportedly containing lead contaminated soils is located in the northern portion of the landfill (USACE, 1993). The suspected source of this contamination was not documented in the prior reports.

Landfill 3 was constructed by excavating a series of trenches oriented east to west across the site. Waste was deposited in the trenches and covered daily with several inches of excavated, native soil. A final cover of 3 to 4 feet of soil was placed over the completed trench cells.

Site Investigations. The initial phase of the investigations conducted at Tinker AFB was conducted by Engineering Science (ES, 1982). The purpose of this study was to conduct a literature search for the various potentially contaminated sites in order to determine from records what was actually disposed of at these sites. ES concluded that Landfill 3 had a moderate potential for contaminant migration.

The second phase involved investigations to confirm the presence of contamination and determine the nature and the extent of contamination at the different sites. In 1983-84, Radian Corporation (Radian) was tasked to perform these investigations. During the Radian study, groundwater was sampled at one existing monitoring well within the landfill, but no significant contamination was detected.

In 1987, the USACE drilled five borings into areas of suspected contamination within Landfill 3. Eight samples were collected for organic and inorganic analyses. Elevated concentrations of volatile organic compounds (VOC), semivolatile organic compounds (SVOC), and metals were found in landfill soils, with the highest concentration of organic contaminants detected in the area of the former sludge dump.

In 1988, the USACE conducted a soils investigation to determine the lateral and vertical extent of organic contamination at the sludge dump. Eight soil samples were collected from 15 borings. Based on the results of this investigation, the USACE contracted with Roy F.

Weston, Inc. to perform a full-scale test of a low temperature thermal treatment system to demonstrate the system's effectiveness in removing VOC and SVOC contamination from the sludge dump soils. During the test, polychlorinated biphenyls (PCB) were discovered in the feed and processed soils. Additional sampling and analysis confirmed the presence of the PCB Aroclor-1260 in excavated soils. The test was discontinued and all excavated soils were placed back in the excavation.

In 1990, the USACE conducted a follow-up investigation in and around the sludge dump area to define the extent of contamination remaining after the discontinued thermal treatment test. Three soil samples were collected from five borings. VOCs, SVOCs, and the PCB Aroclor-1254 were detected in soils.

During the remedial investigation (RI), groundwater samples were collected from soil borings advanced within the landfill. VOCs, SVOCs, and metals were found, with the highest concentration of organic contaminants detected in the area of the former sludge dump.

The USACE sampled groundwater from monitoring wells in the vicinity of the landfill during RI activities from 1986 to 1990. Since 1990, selected monitoring wells have been sampled as part of an on-going groundwater monitoring program. VOCs, SVOCs, and metals have been detected in some samples, but at concentrations significantly below those in groundwater samples from landfill borings.

An exposure assessment was performed to determine the potential human receptors and analyzed the potential exposure pathways at Landfills 1 through 4. Potentially exposed human populations were limited to industrial workers associated with Base operations. The only complete exposure pathways identified during the exposure assessment were inhalation of contaminated soil particles and inhalation of organic vapors from contaminated soil. In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base.

Conclusions. The analytical results of the soils investigations at Landfill 3 revealed the following:

- The sludge dump is the most highly contaminated area within the landfill. It has been characterized with three sampling events summarized in Tables 5-1 through 5-3. In total, 20 VOCs, 11 SVOCs, 1 pesticide/PCB , and 9 metals have been detected at the sludge dump. Three organic and four inorganic compounds were detected at concentrations that exceeded either the SWMU Corrective Action Level (CAL) or U.S. Geological Survey (USGS) background value for that analyte.

- The presence of lead in soil at levels significantly above USGS background concentration was confirmed at the lead-contaminated area. Lead was detected at 480 milligrams per kilogram (mg/kg).

- Lower levels of organic contamination were discovered in two of the three boreholes advanced in the former landfill trenches. No organic compounds were detected in the third boring. Eight metals were detected above USGS background concentrations. Barium, cadmium, chromium, lead, mercury, and zinc were detected at the highest concentrations

The following conclusions can be drawn from the results of the groundwater investigations at the landfill:

- Two groundwater zones were found to exist under Landfill 3: the upper saturated zone (USZ) and the lower saturated zone (LSZ). The USZ flows to the southeast. Two interpretations of the LSZ flow direction were presented in the RI report, one to the southeast and one to the southwest.

- The upper USZ is hydraulically connected to the former trenches and dump sites within the landfill. Analyses performed on USZ groundwater samples collected from soil borings within the landfill detected elevated concentrations of VOCs, SVOCs, metals, and PCBs.

- Although VOCs, SVOCs, and metals were also detected in some groundwater samples from monitoring wells adjacent to Landfill 3, the concentration of contaminants were significantly below those detected in groundwater from landfill borings, indicating that only limited contamination is migrating to groundwater zones outside the landfill.

Recommendations. The following are recommendations to be implemented during the Phase II RFI:

- Install additional monitoring wells in the HWBZ, USZ, and LSZ to characterize and determine the lateral and vertical extent of groundwater contamination originating from Landfill 3.

- Perform aquifer testing to obtain data to evaluate potential transport and migration of contaminants.

- Perform a baseline risk assessment to assess potential impacts to human health and the environment.

- Delineate and monitor the Hennessey water bearing zone (HWBZ) and USZ separately as opposed to the USZ as currently defined in this report, which includes both zones.

- Determine the direction of localized groundwater flow within the HWBZ, USZ, and LSZ.

- Collect site-specific soil background samples to be used in addition to USGS soil data to distinguish site-related from background concentrations in a statistically significant manner during the Phase II investigation.

1.0 Introduction

1.1 Purpose and Scope

This document has been prepared in response to the U.S. Department of the Air Force, Tinker Air Force Base (AFB), Oklahoma request for a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Summary Report for solid waste management unit (SWMU)-5, Landfill No. 3 (Landfill 3).

The objective of this RFI Summary Report is to provide Tinker AFB with one comprehensive report that summarizes the various investigations that have occurred at Landfill 3 since the first environmental investigation was initiated on Base in 1981. The purpose of this comprehensive summary document is to:

- Characterize the site (Environmental Setting).
- Define the source (Source Characterization).
- Define the degree and extent of contamination (Contamination Characterization).
- Identify actual or potential receptors.
- Identify all action levels for the protection of human health and the environment.

Additionally, this document briefly describes the procedures, methods, and results of all previous investigations, remedial actions, and baseline risk assessment that relate to Landfill 3 and contaminant releases, including information on the type and extent of contamination at the site, and actual or potential receptors. Where previous investigations, reports, or studies were not comprehensive and did not furnish the information required to determine the nature and extent of contamination, future work that can be conducted to complete the investigation has been recommended.

1.2 Preface

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to address the cleanup of hazardous waste disposal sites across the country. CERCLA gave the president authority to require responsible parties to remediate the sites or to undertake response actions through use of a fund (the Superfund). The president, through Executive Order 12580, delegated the U.S. Environmental Protection Agency (EPA) with the responsibility to investigate and remediate private party hazardous waste disposal sites that created a threat to human health and the environment. The president delegated responsibility for investigation and cleanup of federal facility disposal sites to the various federal agency heads. The Defense Environmental Restoration Program (DERP) was formally established by Congress in Title 10 U.S. Code (USC) 2701-2707 and 2810. DERP provides centralized management for the cleanup of U.S. Department of Defense (DOD) hazardous waste sites consistent with the provisions of CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations [CFR] 300), and Executive Order 12580. To support the goals of DERP, the Installation Restoration Program (IRP) was developed to identify, investigate, and clean up contamination at installations.

Under the Air Force IRP, Tinker AFB began a Phase I study similar to a preliminary assessment/site investigation (PA/SI) in 1981 (Engineering Science [ES], 1982). This study helped locate 14 sites that needed further investigation. Phase II studies were performed in 1983 (Radian Corporation [Radian], 1985a,b).

In 1986, Congress amended CERCLA through SARA. SARA waived sovereign immunity for federal facilities. This act gave EPA authority to oversee the cleanup of federal facilities and to have the final authority for selecting the remedial action at federal facilities placed on the National Priorities List (NPL) if the EPA and the relevant federal agency cannot concur in the selection. Congress also codified DERP (SARA Section 211), establishing a fund for the DOD to remediate its sites because the Superfund is not available for the cleanup of federal facilities. DERP specifies the type of cleanup responses that the fund can be used to address.

In response to SARA, the DOD realigned its IRP to follow the investigation and cleanup stages of the EPA:

- PA/SI
- Remedial investigation/feasibility study (RI/FS)
- Record of Decision (ROD) for selection of a remedial action
- Remedial design/remedial action.

In 1984, Congress amended RCRA with the Hazardous and Solid Waste Amendments (HSWA) which allow the EPA to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or constituents from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989 Tinker AFB submitted its Part B permit application for renewal of its operating RCRA hazardous waste storage facility permit.

EPA, in the Hazardous Waste Management Permit for Tinker AFB, dated July 1, 1991, identified 43 SWMUs and two areas of concern (AOC) on Tinker AFB that need to be addressed. This permit requires Tinker AFB to investigate all SWMUs and AOCs and to perform corrective action at those identified as posing a threat to human health or the environment. This RFI Summary Report has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 3 and to document all determinations.

1.3 Facility Description

Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County (Figure 1-1) with its approximate geographic center located at 35° 25' latitude and 97° 24' longitude (U.S. Geological Survey [USGS], 1978). The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south (Figure 1-2). An additional area east of the main Base is used by the Engineering Installation Division (EID) and is known as Area D. The Base encompasses approximately 5,000 acres. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon™, jet fuels, and radium paints. Wastes that are currently generated are managed at two permitted hazardous waste storage facilities. However, prior to enactment of RCRA, industrial wastes were discharged into unlined landfills and waste pits, streams, sewers, and ponds. Past releases from these landfills, pits, etc., as well as from underground tanks, have occurred. As a result, there are numerous sites of soil, groundwater, and surface water contamination on the Base.

The various reports generated as a result of investigative activities conducted at the Landfill 3 have been reviewed and evaluated in terms of the sites' status under RCRA regulations. A summary based on the review of these reports for Landfill 3 is presented in the following chapters and sections. In addition, recommendations for additional work is given at the end of the summary report.

1.4 Site Description

Landfill 3 occupies approximately 8.25 acres and is located in the southwest corner of Tinker AFB. The landfill is just north of Landfill Road, bordering Crutcho Creek to the north and

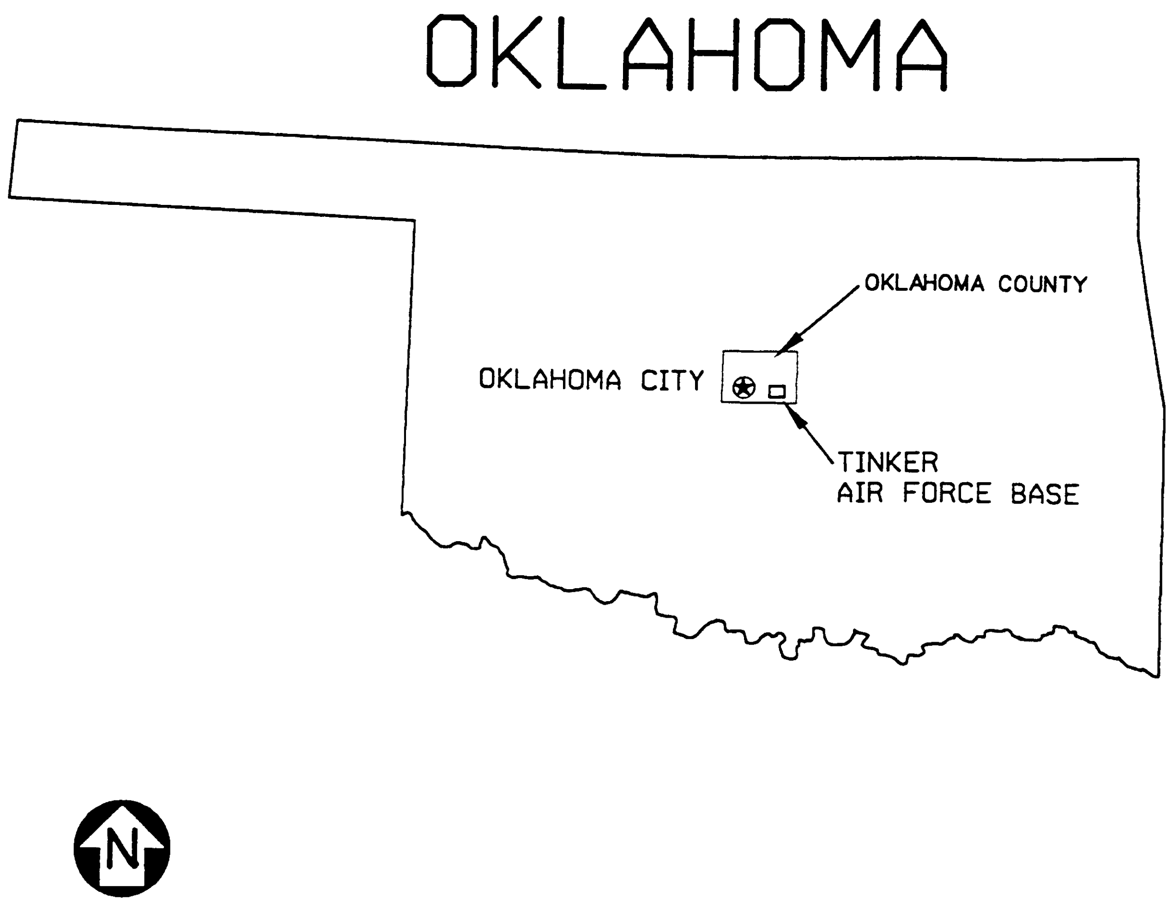

FIGURE 1-1
TINKER AIR FORCE BASE
OKLAHOMA
STATE INDEX MAP

PREPARED FOR
TINKER AFB
OKLAHOMA

STARTING DATE: 03/17/94	DATE LAST REV.:	DRAFT. CHCK. BY:G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY:P.O. TERRY	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.:J. TAYLOR	PROJ. NO.:

3/23/94 POT
FILENAME: G:\TINKER\40983202.075

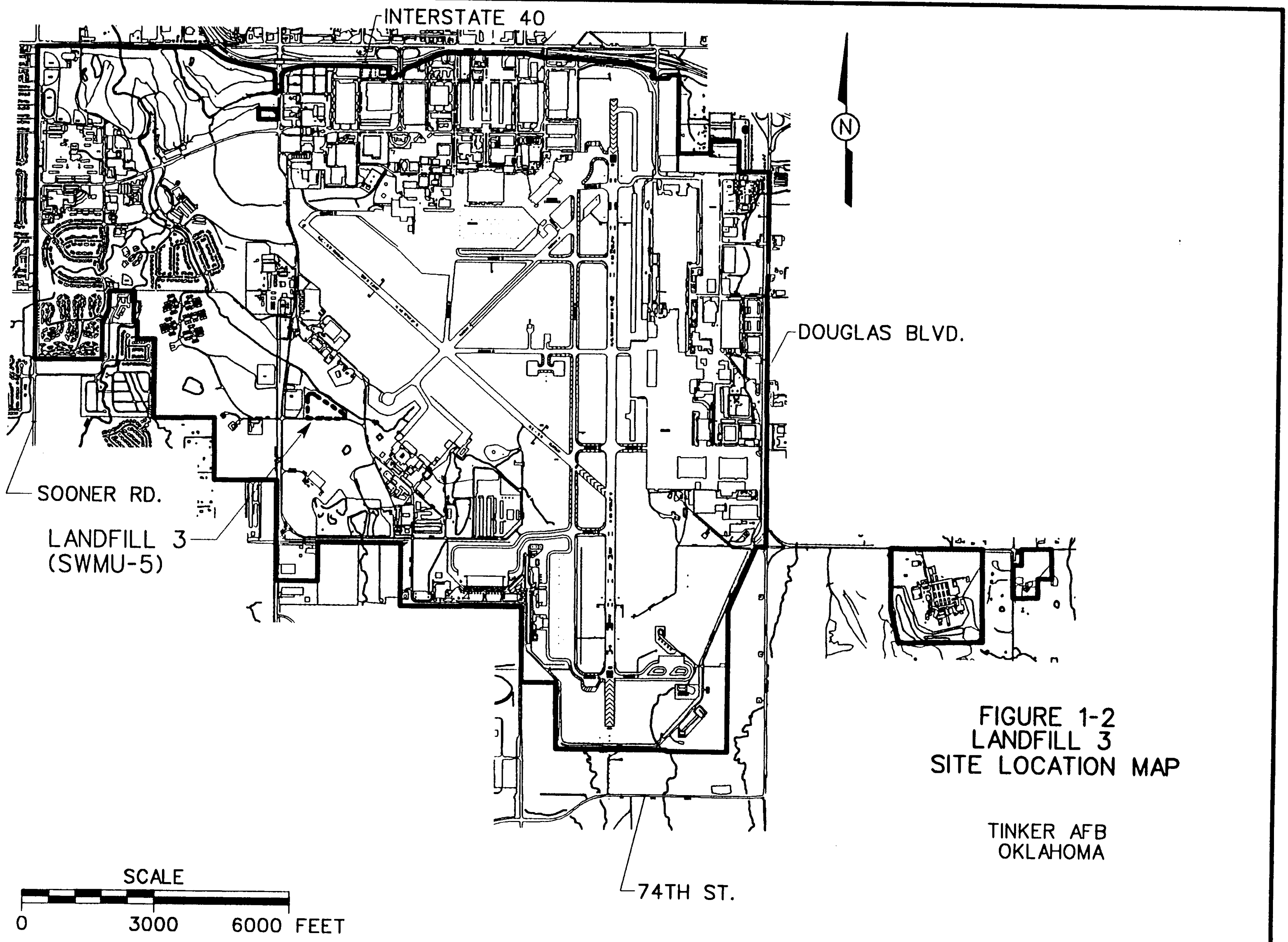

FIGURE 1-2
LANDFILL 3
SITE LOCATION MAP

TINKER AFB
OKLAHOMA

STARTING DATE: 3/21/94	DATE LAST REV.:	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P.O. TERRY	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

FILENAME: G:\TINKER\40983202.083

east, and Building 1022 to the west. The sample locations of Landfill 3 are shown in Figure 1-3.

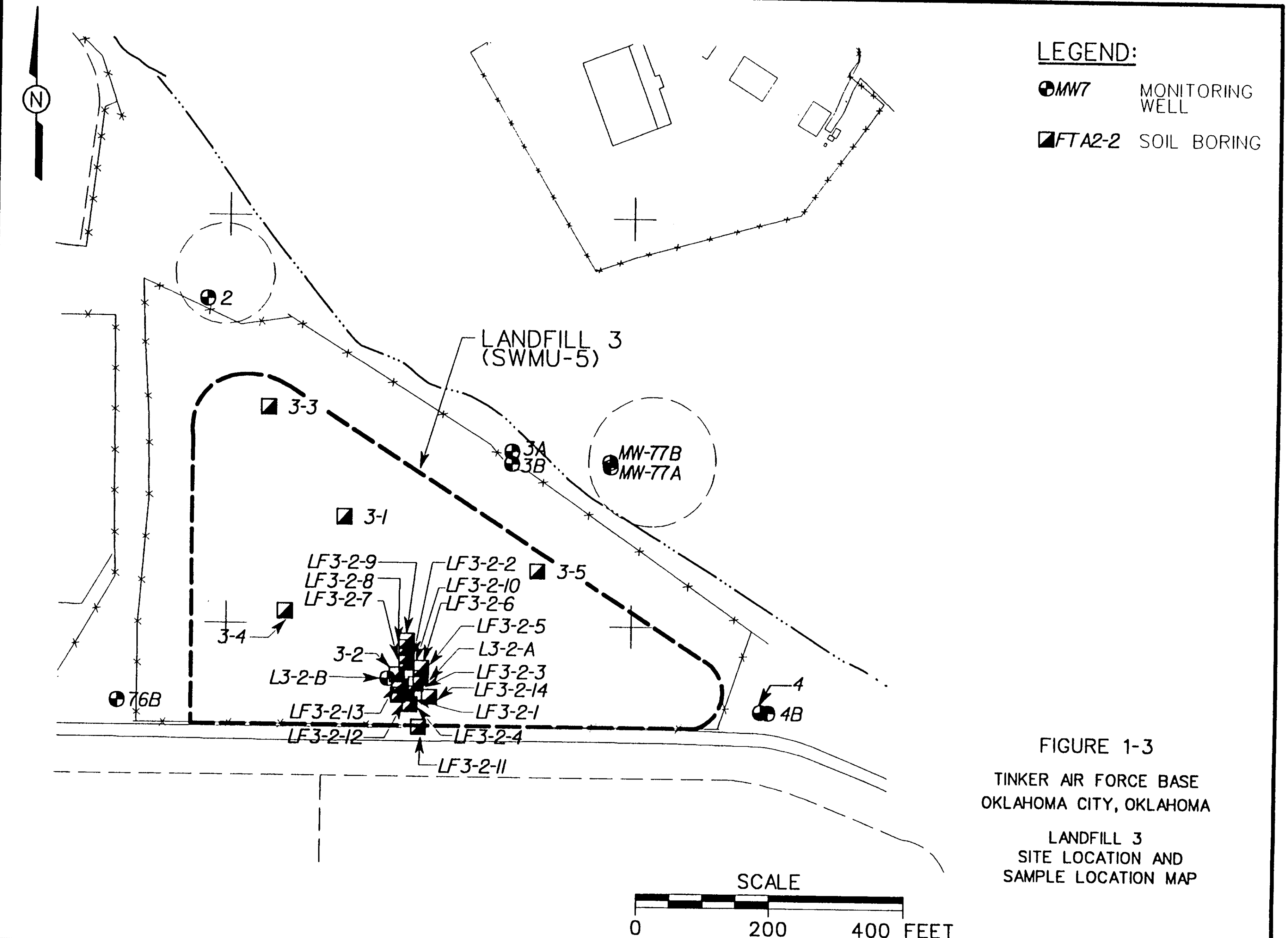

FIGURE 1-3

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 3
SITE LOCATION AND
SAMPLE LOCATION MAP

STARTING DATE: 01/15/94	DATE LAST REV.: / /	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: LLS	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

03/25/94 P01
FILENAME: G:\TINKER\40983202.006

2.0 Background

2.1 Site Operations and History

Tinker AFB was originally known as the Midwest Air Depot and began operations in July 1941. The site was activated March 1942. During World War II, the depot was responsible for reconditioning, modifying, and modernizing aircraft, vehicles, and equipment.

General refuse generated from these operations has been disposed of in at least six landfills located on the Base property or leased land adjacent to the Base. Landfill 3 was active from 1952 to 1961 and was used primarily for the disposal of general refuse, although paint buckets, insecticide cans, and barrels have been found in the landfill trenches. A number of low-level radioactive vacuum tubes were also buried at the site. Two specific-use dump areas were known or suspected to exist within the boundaries of Landfill 3.

- A sludge dump, located in the south-central area of the landfill, was in use from 1961 to 1968. This dump is reported to contain waste oils and other liquids from industrial operations at Building 3001 and waste fuels and sludge from the Petroleum Oil Lubricant (POL) Facility (U.S. Army Corps of Engineers [USACE], 1989).

- An area reportedly containing lead-contaminated soils is located in the northern portion of the landfill (USACE, 1993). The suspected source of this contamination was not documented in the prior reports.

Approximately 180,000 cubic yards (yd^3) of waste materials are estimated to have been deposited in Landfill 3. After the area was actively used as a landfill, it served for a time as a storage area for dirt and construction rubble.

An 8-acre landfill cap, designed in accordance with EPA technical guidelines, was constructed as an interim remedial action and completed in December 1991.

2.2 Summary of Previous Investigations

Engineering Science, Inc. Landfill 3 was among 14 sites identified during the IRP Phase I assessment completed by ES in April 1982. The purpose of the study was to identify the potential for contamination from past waste disposal practices and to assess the potential for contaminant migration. ES's work scope included activities such as reviewing site records, interviewing personnel, defining the environmental setting, and determining quantities and locations of current and past hazardous waste storage, treatment, and disposal. ES assigned a hazardous assessment rating methodology (HARM) score of 60 to the site, and ranked the site as a priority 5 of 14. ES concluded that Landfill 3 had a moderate potential for contaminant migration.

Radian Corporation. IRP Phase II field investigations were initiated in 1983 by Radian Corporation. The purpose of these efforts was to determine if any environmental contamination had occurred due to disposal and management practices at the sites identified in the Phase I report by ES. Radian's Phase II, Stage 1 field activities conducted during February 1984 did not involve the installation of any new monitoring wells or exploratory borings at Landfill 3. Groundwater sampling at the one existing monitoring well within Landfill 3 did not detect any significant contamination.

Radian's Phase II, Stage 2 field activities conducted from June through October 1984 focused on areas of contamination discovered during the Phase II, Stage 1 field work and, therefore, did not involve any additional groundwater testing or soil borings at Landfill 3. Radian did collect sediment samples along Crutcho Creek. One sample collected along the creek downstream of Landfill 3 showed no elevated levels of industrial contaminants.

U.S. Army Corps of Engineers. Tinker AFB employed the USACE from 1986 to 1990 to conduct a remedial investigation (RI) of Landfills 1 through 4 (SWMUs 3 through 6) (USACE, 1993). The USACE assessed the magnitude and extent of contamination originating from the landfill trenches. The RI scope of work included records searches, subsurface geologic explorations, installation and sampling of monitoring wells, sampling of water and solid waste from landfill trenches, and explorations to determine the extent of the waste boundary.

During RI activities performed by the USACE, samples were obtained from 25 soil borings drilled into Landfill 3. The soil samples were collected at various times and were not all analyzed for the same array of chemical constituents. The following analytes were among the parameters tested: volatile organic compounds (VOC), semivolatile organic compounds (SVOC), metals, pesticides, polychlorinated biphenyls (PCB), extraction procedure (EP) toxicity metals, phenols, total petroleum hydrocarbon (TPH), total organic carbon (TOC), cyanide, pH, and conductivity. VOCs, SVOCs, metals, and PCBs were detected in Landfill 3 soils.

Groundwater quality in the vicinity of Landfill 3 was investigated by sampling groundwater from soil borings within the landfill and from selected groundwater monitoring wells adjacent to the landfill. Hydrogeological studies determined that two groundwater aquifers, now classified as the upper saturated zone (USZ) and the lower saturated zone (LSZ), exist under Landfill 3. Groundwater samples were collected from eight borings to characterize the contamination within the USZ in the vicinity of the former landfill trenches (borings L3-3, L3-4, and L3-5), the sludge dump (borings L3-2-A, L3-7, L3-9, and L3-11), and the lead-contaminated area (boring L3-1).

Monitoring wells screened in the USZ and LSZ were sampled to determine the magnitude and extent of contaminant migration. Monitoring wells 2A, 3A, 4A, and 76A are adjacent to the landfill in the USZ and monitoring wells 4B and 76B are adjacent to the landfill in the LSZ. The USZ groundwater within the landfill was found to be contaminated with VOCs, SVOCs, and metals. The USZ and LSZ groundwater adjacent of the landfill was also contaminated with VOCs, SVOCs, and metals, but the concentrations detected were significantly lower than those found in the landfill.

In June 1990, the U.S. Air Force issued a decision document on the cover system design for Landfill 3. The cover designs analyzed by B&V Waste Science and Technology Corporation (B&V) in the August 1989 design cost comparison study were modified because EPA determined in January 1989 that Landfill 3 would be included in a Part B, RCRA permit for the Base. Incorporation of RCRA requirements mandated some design modifications.

In February 1991, the USACE issued a preliminary draft baseline risk assessment for Landfills 1 through 4 (USACE, 1991). At these landfill sites, seven organic chemicals and two inorganic chemicals were determined to be chemicals of potential concern. Inhalation of contaminated particles and inhalation of organic vapors were the only completed exposure pathways identified in the risk assessment. Industrial site workers were the only potentially exposed population. All carcinogenic and noncarcinogenic risks associated with the site were within acceptable risk levels for CERCLA sites.

PRC Environmental Management, Inc. (PRC). PRC performed a RCRA Facility Assessment (RFA) in 1989 to identify and assess the potential for release of hazardous waste or hazardous constituents from SWMUs and AOCs, as well as to evaluate the need for further investigations under the authority of Section 3004(u) of RCRA, as amended by the HSWA of 1984. The RFA report incorporated the results of a review of the file materials available from EPA Region VI and a visual site inspection performed May 15 through 19, 1989. The assessment of Landfill 3 concluded that there was a high potential for release of hazardous waste or hazardous constituents to soil and groundwater; a low potential for releases to surface water; a moderate potential for releases to air; and high potential for the generation of subsurface gas.

Roy F. Weston, Inc. In 1989, the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) commissioned Weston to conduct a full-scale demonstration of their patented low temperature thermal treatment system to remove jet petroleum grade 4 (JP-4) and other VOCs from contaminated soils at the Landfill 3 sludge dump area. Weston had previously conducted a pilot investigation of low temperature thermal stripping of VOCs from sludge dump soil and issued a report at the conclusion of this work in 1986. During the full-scale demonstration test, Weston excavated approximately 3,000 yd^3 of material from the sludge dump area (Weston, 1990a). Approximately 70 yd^3 of soil was treated before PCBs were discovered in the feed and treated soil. The demonstration test was immediately discontinued because the research development and demonstration (RD&D) permit did not allow the processing of PCB-contaminated soil. PCB concentrations were 24 to 270 parts per million (ppm) in the excavated soil and 5,900 ppm in the sludge. Weston subsequently prepared an exit plan and a decontamination plan for the site (Weston, 1990b). The excavated soils were returned to the original excavation and then covered with a clay cap, approximately 2 feet thick, to minimize the potential for mobilization of PCB contaminated soils.

In October to December 1992, Weston sampled groundwater at selected monitoring wells within the Base.

B&V Waste Science and Technology Corporation. Tinker AFB employed B&V in 1989 to evaluate alternative cover systems for Landfill 3 and investigate the need to relocate utility systems in the vicinity of the landfill. B&V recommended a natural soil cover with synthetic water barrier and gas control layers. The study indicated that no utilities were located in the immediate vicinity of Landfill 3.

In 1990, B&V issued a design analysis report and construction specifications for the selected cover at Landfill 3 (B&V, 1990a,b). The design consisted of a fill layer to achieve a 3 to 5 percent initial slope, a 24-inch compacted clay layer with a permeability less than or equal to 10^{-7} centimeters per second (cm/s), a flexible membrane liner, a synthetic drainage net, filter fabric, an 18-inch layer of fill, and 6 inches of top soil with vegetation. The cover system selected by USACE was a modification of one of the original alternatives analyzed by B&V.

2.3 Current Regulatory Status

The IRP has been ongoing at Tinker AFB since the early 1980s. IRP studies on the Base were conducted according to IRP guidance, which is essentially the same as EPA's guidance for conducting RI/FS under CERCLA. All investigation and removal actions have been closely monitored and approved by the EPA.

Since receiving the Hazardous Waste Management Permit on July 1, 1991, many of the IRP sites have come under the jurisdiction of the RCRA permits branch of EPA. As such, they have been identified as SWMUs; however, a large amount of work has already been performed at most of these sites under the IRP. Additional investigation at the SWMUs will be performed under the IRP.

3.0 Environmental Setting

3.1 Topography and Drainage

3.1.1 Topography

Regional/Tinker AFB. The topography of Oklahoma City and surrounding area varies from generally level to gently rolling in appearance. Local relief is primarily the result of dissection by erosional activity or stream channel development. At Oklahoma City, surface elevations are typically in the range of 1,070 to 1,400 feet mean sea level (msl). At Tinker AFB, ground surface elevations vary from 1,190 feet msl near the northwest corner where Crutcho Creek intersects the Base boundary to approximately 1,320 feet msl at Area D (EID).

Site. Landfill 3 is located in the southwest corner of Tinker AFB. The landfill ranges in elevation from 1,231 feet msl at boring L3-3 in the northern portion of the landfill to 1,222 feet msl at boring L3-5 along the southeast boundary of the landfill. At boring L3-4, located in the eastern portion of Landfill 3, the elevation was reported to be 1,229 feet msl. An interim remedial action to construct an 8-acre cap over Landfill 3 was completed in December 1991. The cap was designed to RCRA standards.

3.1.2 Surface Drainage

Regional/Tinker AFB. Drainage of Tinker AFB land areas is accomplished by overland flow of runoff to diversion structures and then to area surface streams, which flow intermittently. The northeast portion of the Base is drained primarily by unnamed tributaries of Soldier Creek, which is itself a tributary of Crutcho Creek. The north and west sections of the Base, including the main instrument runway, drain to Crutcho Creek, a tributary of the North Canadian River. Two small unnamed intermittent streams crossing installation boundaries south of the main instrument runway generally do not receive significant quantities of Base runoff due to site grading designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

Site. Surface drainage in the vicinity of Landfill 3 is influenced by the engineered clay cap in place at the site. The cap was designed to divert surface drainage away from the landfill to a centrally located drainage ditch, as well as to ditches along the perimeter of the cap.

Ultimately, surface drainage is intercepted by tributaries leading to Stanley Draper Lake, south of Tinker AFB.

3.2 Geology

3.2.1 Regional/Tinker AFB Geology

Tinker AFB is located within the Central Redland Plain Section of the Central Lowland physiographic province, which is tectonically stable. No major fault or fracture zones have been mapped near Tinker AFB. The major lithologic units in the area of the Base are relatively flat-lying and have a regional westward dip of about 0.0076 foot per foot (ft/ft) (Bingham and Moore, 1975).

Geologic formations that underlie Tinker AFB include, from oldest to youngest, the Wellington Formation, Garber Sandstone, and the Hennessey Group; all are Permian in age.

All geologic units immediately underlying Tinker AFB are sedimentary in origin. The Garber Sandstone and Wellington Formation are commonly referred to as the Garber-Wellington Formation due to strong lithologic similarities. These formations are characterized by fine-grained, calcareously-cemented sandstones interbedded with shale. The Hennessey Group consists of the Fairmont Shale and the Kingman Siltstone. It overlies the Garber-Wellington Formation along the eastern portion of Cleveland and Oklahoma counties. Quaternary alluvium is found in many undisturbed streambeds and channels located within the area.

Stratigraphy. Tinker AFB lies atop a sedimentary rock column composed of strata that ranges in age from Cambrian to Permian above a Precambrian igneous basement. Quaternary alluvium and terrace deposits can be found overlying bedrock in and near present-day stream valleys. At Tinker AFB, Quaternary deposits consist of unconsolidated weathered bedrock, fill material, wind-blown sand, and interfingering lenses of sand, silt, clay, and gravel of fluvial origin. The terrace deposits are exposed where stream valleys have downcut through older strata and have left them topographically above present-day deposits. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

Subsurface (bedrock) geologic units which outcrop at Tinker AFB and are important to understanding groundwater and contaminant concerns at the Base consist of, in descending order, the Hennessey Group, the Garber Sandstone, and the Wellington Formation (Table 3-1).

Table 3-1

Major Geologic Units in the Vicinity of Tinker AFB (Modified from Wood and Burton, 1968)

(Page 1 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	PLEISTOCENE AND RECENT	Alluvium	0-70	Unconsolidated and interfingering lenses of sand, silt, clay, and gravel in the flood plains and channels of stream	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines.
		Terrace deposits	0-100	Unconsolidated and interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above the flood plains of the principal streams.	Moderately permeable. Locally above the water table and not saturated. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

Table 3-1

(Page 2 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
PERMIAN	LOWER PERMIAN	Hennessey Group (includes Kingman Siltstone and Fairmont Shale)	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places water contains large amounts of sulfate.
		Garber Sandstone	500$\pm$	Deep-red clay to reddish-orange, massive and cross-bedded fine-grained sandstone interbedded and interfingered with red shale and siltstone	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500$\pm$	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

These bedrock units were deposited during the Permian Age (230 to 280 million years ago) and are typical of redbed deposits formed during that period. They are composed of a conformable sequence of sandstones, siltstones, and shales. Individual beds are lenticular and vary in thickness over short horizontal distances. Because lithologies are similar and because of a lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are often informally lumped together as the Garber-Wellington Formation. Together, they are about 900 feet thick at Tinker AFB. The interconnected, lenticular nature of sandstones within the sequence forms complex pathways for groundwater movement.

The surficial geology of the north section of the Base is dominated by the Garber Sandstone, which outcrops across a board area of Oklahoma County. Generally, the Garber outcrop is covered by a veneer of soil and/or alluvium up to 20 feet thick. To the south, the Garber Sandstone is overlain by outcropping strata of the Hennessey Group, including the Kingman Siltstone and the Fairmont Shale (Bingham and Moore, 1975). Drilling information obtained as a result of geotechnical investigations and monitoring well installation confirms the presence of these units.

Depositional Environment. The Permian-age strata presently exposed at the surface in central Oklahoma were deposited along a low-lying north-south oriented coastline. Land features included meandering to braided sediment-loaded streams that flowed generally westward from highlands to the east (ancestral Ozarks). Sand dunes were common, as were cut-off stream segments that rapidly evaporated. The climate was arid and vegetation sparse. Off shore the sea was shallow and deepened gradually to the west. The shoreline's position varied over a wide range. Isolated evaporitic basins frequently formed as the shoreline shifted.

Across Oklahoma, this depositional environment resulted in an interfingering collage of fluviatile and wind-blown sands, clays, shallow marine shales, and evaporite deposits. The overloaded streams and evaporitic basins acted as sumps for heavy metals such as iron, chromium, lead, and barium. Oxidation of iron in the arid climate resulted in the reddish color of many of the sediments. Erosion and chemical breakdown of granitic rocks from the highlands resulted in extensive clay deposits. Evaporite minerals such as anhydrite ($CaSO_4$), barite ($BaSO_4$), and gypsum ($CaSO_4 \bullet 2H_2O$) are common.

Around Tinker AFB, the Hennessey Group represents deposition in a tidal flat environment cut by shallow, narrow channels. The Hennessey Group is comprised predominantly of red shales which contain thin beds of sandstone (less than 10 feet thick) and siltstone. In outcrop, "mudball" conglomerates, burrow surfaces, and dessication cracks are recognized. These units outcrop over roughly the southern half of the Base, thickening to approximately 70 feet in the southwest from their erosional edge (zero thickness) across the central part of Tinker AFB.

In contrast, the Garber Sandstone and the Wellington Formation around Tinker AFB consist of an irregularly-interbedded system of lenticular sandstones, siltstones, and shales deposited either in meandering streams in the upper reaches of a delta or in a braided stream environment. Outcrop units north of Tinker AFB exhibit many small to medium channels with cut and fill geometries consistent with a stream setting. Sandstones are typically cross-bedded. Individual beds range in thickness from a few inches to approximately 50 feet and appear massive, but thicker units are often formed from a series of "stacked" thinner beds. Geophysical and lithologic well logs indicate that from 65 to 75 percent of the Garber Sandstone and the Wellington Formation are composed of sandstone at Tinker AFB. The percentage of sandstone in the section decreases to the north, south, and west of the Base. These sandstones are typically fine to very fine grained, friable, and poorly cemented. However, where sandstone is cemented by red muds or by secondary carbonate or iron cements, local thin "hard" intervals exist along disconformities at the base of sandstone beds. Shales are described as ranging from clayey to sandy, are generally discontinuous, and range in thickness from a few inches to approximately 40 feet.

Stratigraphic Correlation. Correlation of geologic units is difficult due to the discontinuous nature of the sandstone and shale beds. However, cross-sections (Figure 3-1) demonstrate that two stratigraphic intervals can be correlated over large sections of the Base in the conceptual model. These intervals are represented on geologic cross-sections A-A' and B-B' (Figures 3-2 and 3-3). Section A-A' is roughly a dip section and B-B' is approximately a strike section. The first correlatable interval is marked by the base of the Hennessey Group and the first sandstone at the top of the Garber Sandstone. This interval is mappable over the southern half of Tinker AFB. The second interval consists of a shale zone within the Garber Sandstone which, in places, is comprised of a single shale layer and, in other places, of multiple shale layers. This interval is more continuous than other shale intervals and in cross-sections appears mappable over a large part of the Base. It is extrapolated under the central portion of Tinker AFB where little well controls exists.

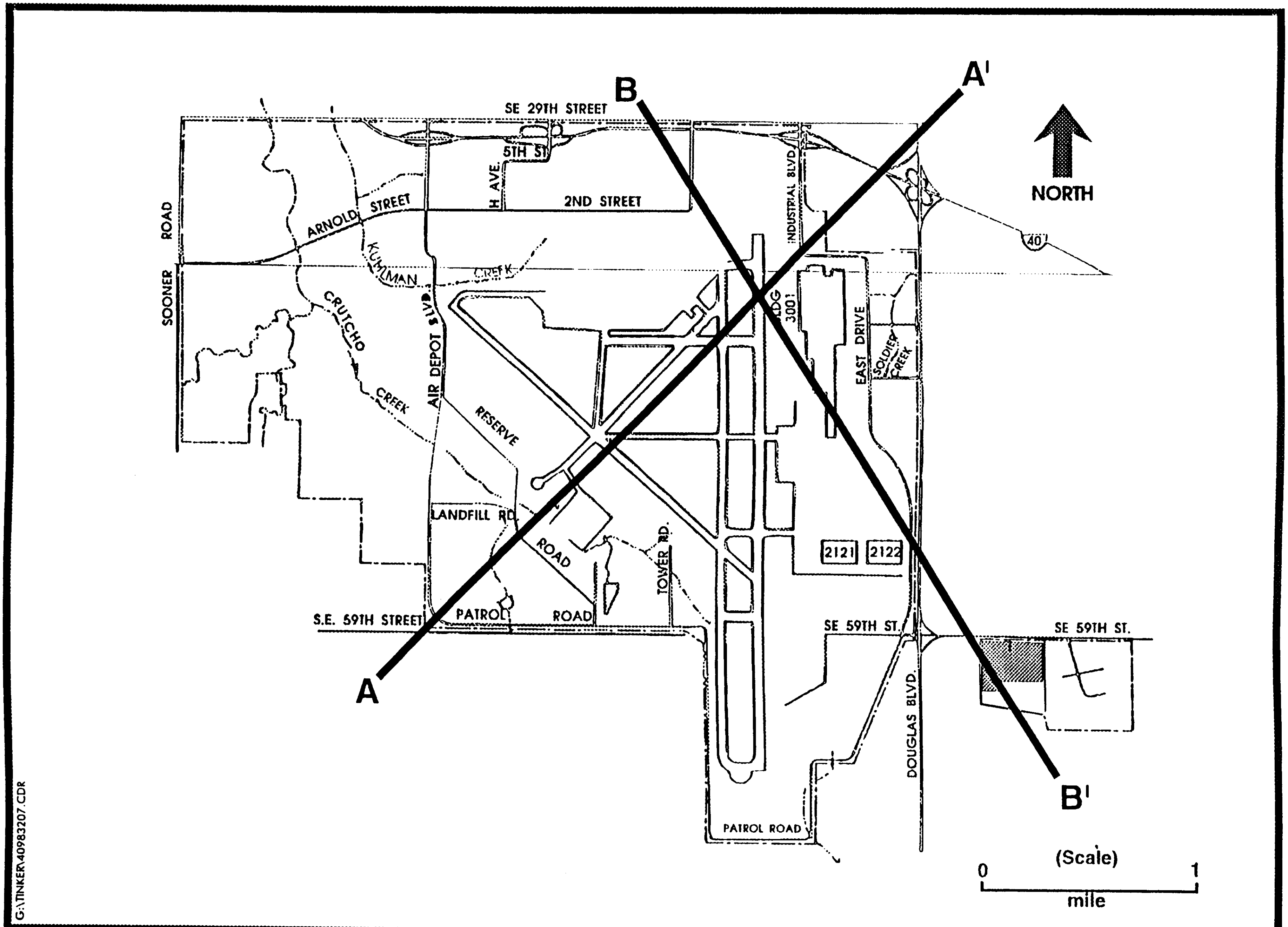

FIGURE 3-1 TINKER AFB GEOLOGIC CROSS SECTION LOCATION MAP

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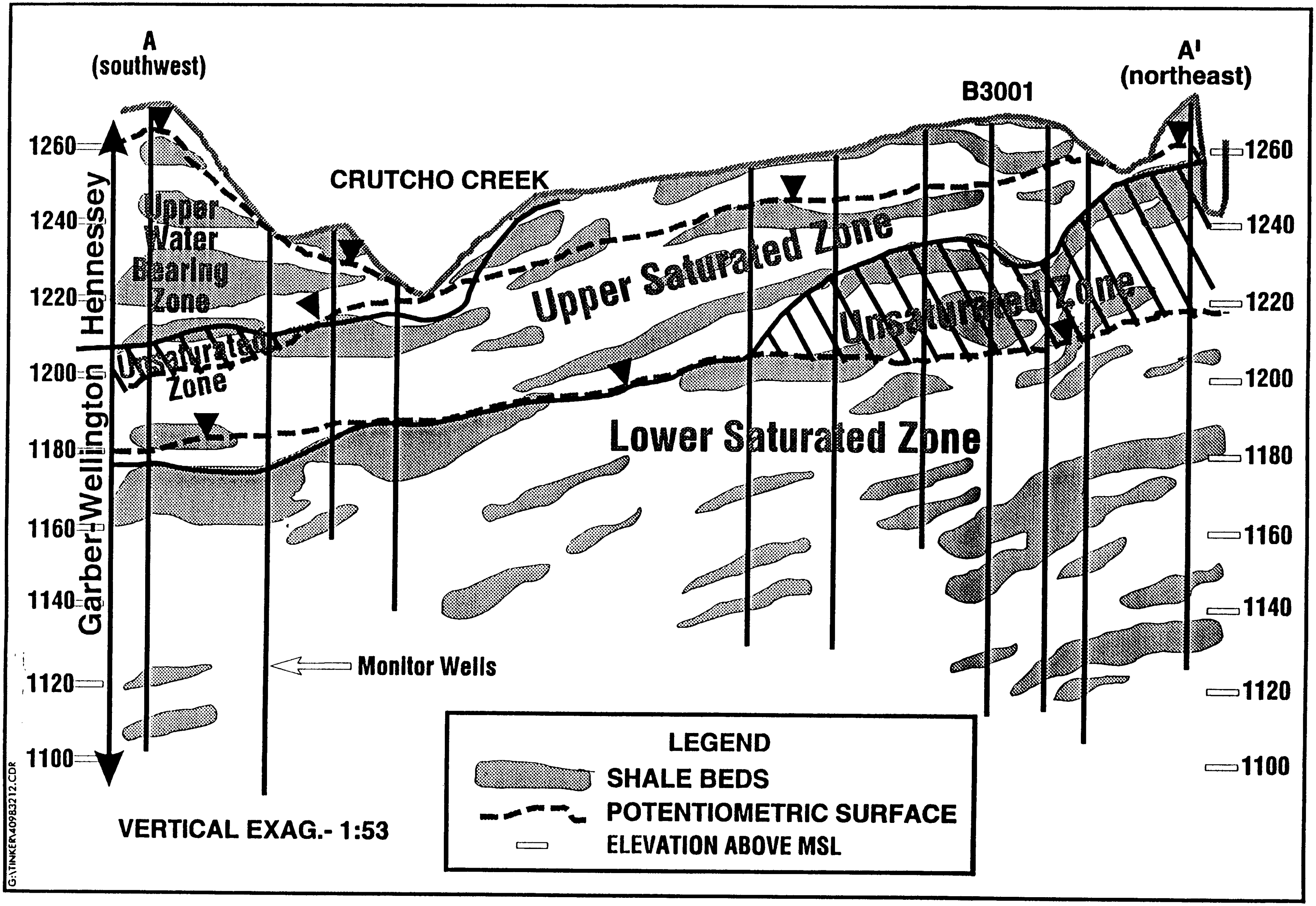


FIGURE 3-2 TINKER AFB GEOLOGIC CROSS SECTION A-A'

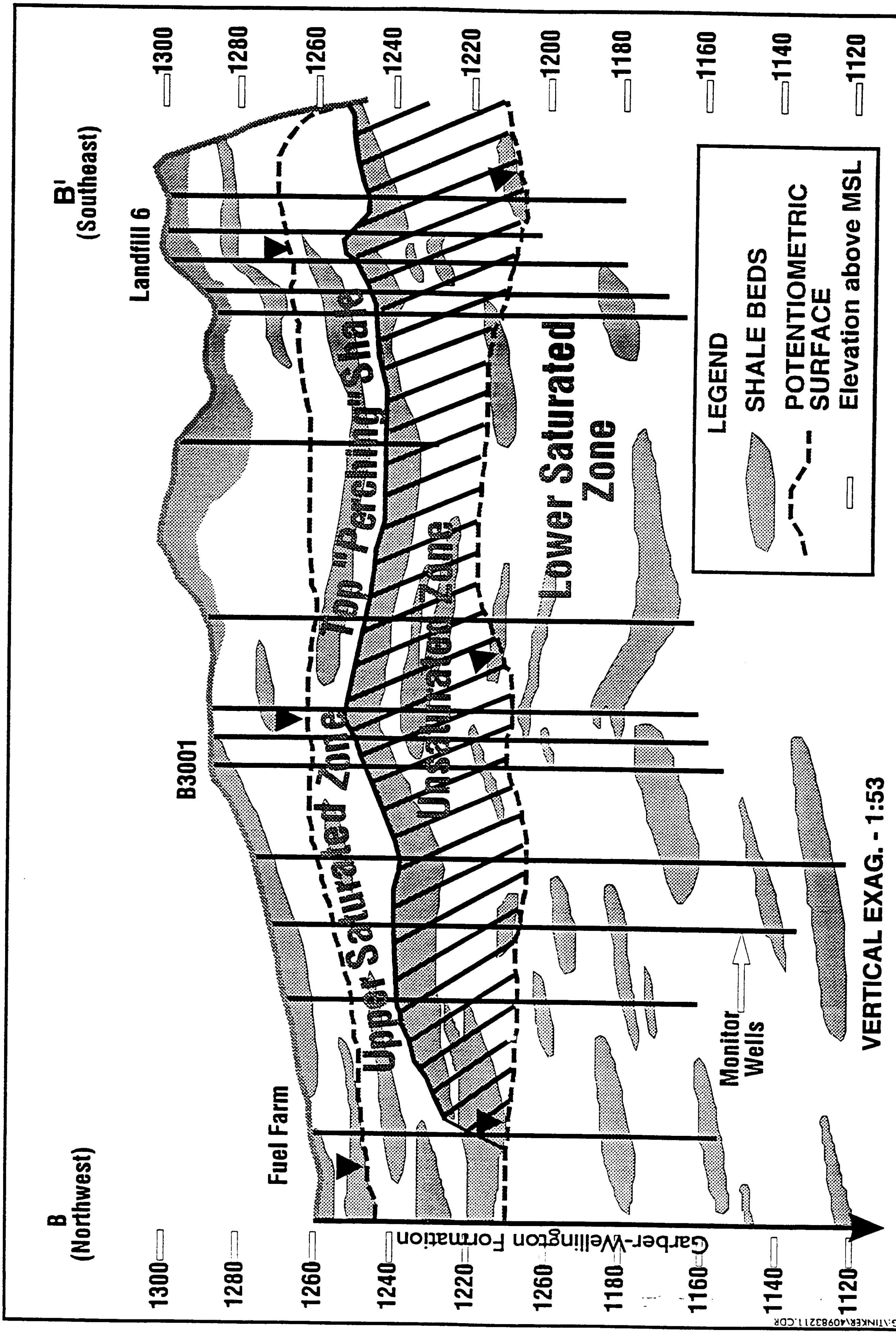


FIGURE 3-3 TINKER AFB GEOLOGIC CROSS SECTION B-B'

Structure. Tinker AFB lies within a tectonically stable area; no major near-surface faults or fracture zones have been mapped near the Base. Most of the consolidated rock units of the Oklahoma City area dip westward at a low angle. A regional dip of 0.0057 to 0.0076 ft/ft in a generally westward direction is supported by stratigraphic correlation on geologic cross-sections at Tinker AFB. Bedrock units strike slightly west of north.

Although Tinker AFB lies in a tectonically stable area, regional dips are interrupted by buried structural features located west of the Base. A published east-to-west generalized geologic cross-section, which includes Tinker AFB, supports the existence of a northwest-trending structural trough or syncline located near the western margin of the base. The syncline is mapped adjacent to and just east of a faulted anticlinal structure located beneath the Oklahoma City Oil Field. The fault does not appear to offset Permian-age strata. There are indications that the syncline may act as a "sink" for some regional groundwater (southwest flow) at Tinker AFB before it continues to more distant discharge points.

3.2.2 Site Geology

Landfill 3 is located just south of the contact between the Hennessey Group and the Garber-Wellington Formation. Alluvial deposits (sands, silts, and clays) of varying thickness exist in the shallow subsurface of the Landfill 3 area, extending from the surface down to a depth ranging from 5 to 15 feet below grade. These fined grained materials exist below the portions of the Landfill 3 trenches where the Hennessey shale is nonexistent. During the RI (USACE, 1993), wastes were discovered in the trench areas just below the cover material; these wastes ranged in thickness from a few feet to 18 feet before shale was encountered. The underlying shale interval pinches out north of Landfill Road at approximately borehole L3-1. The landfill trenches within the southern section of Landfill 3 are underlain by this shale layer, while the trenches north of the pinch zone are set within and underlain by clay.

3.3 Hydrology

3.3.1 Regional/Tinker AFB Hydrology

The most important source of potable groundwater in the Oklahoma City metropolitan area is the Central Oklahoma aquifer system. This aquifer extends under much of central Oklahoma and includes water in the Garber Sandstone and Wellington Formation, the overlying alluvium and terrace deposits, and the underlying Chase, Council Grove, and Admire Groups. The Garber Sandstone and the Wellington Formation portion of the Central Oklahoma aquifer system is commonly referred to as the "Garber-Wellington aquifer" and is considered to be a single aquifer because these units were deposited under similar conditions and because many of the best producing wells are completed in this zone. On a regional scale, the aquifer is confined above by the less permeable Hennessey Group and below by the Late Pennsylvanian Vanoss Group.

Tinker AFB lies within the limits of the Garber-Wellington Groundwater Basin. Currently, Tinker derives most of its water supply from this aquifer and supplements the supply by purchasing from the Oklahoma City Water Department. The nearby communities of Midwest City and Del City derive water supplies from both surface sources and wells tapping the aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by a municipal distribution system also depend on the Garber-Wellington aquifer. Communities presently depending upon surface supplies (such as Oklahoma City) also maintain a well system drilled into the Garber-Wellington as a standby source of water in the event of drought.

Recharge of the Garber-Wellington aquifer is accomplished principally by percolation of surface waters crossing the area of outcrop and by rainfall infiltration in this same area. Because most of Tinker AFB is located in an aquifer outcrop area, the Base is considered to be situated in a recharge zone.

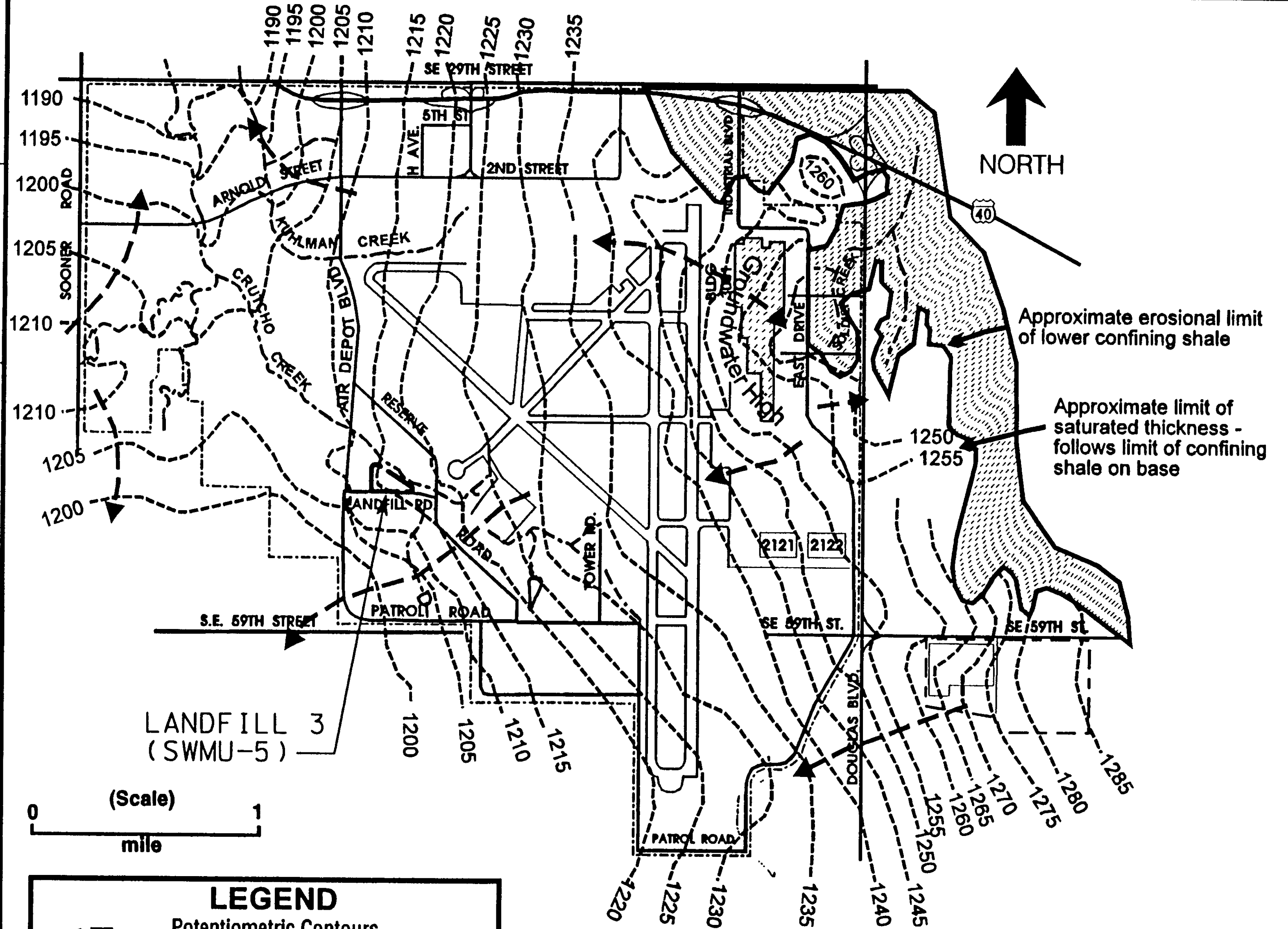
According to Wood and Burton (1968) and Wickersham (1979), the quality of groundwater derived from the Garber-Wellington aquifer is generally good, although wide variations in the concentrations of some constituents are known to occur. Wells drilled to excessive depths may encounter a saline zone, generally greater than 900 feet below ground surface. Wells drilled to such depths or those accidentally encountering the saline zone are either grouted over the lowest screens or may be abandoned.

Tinker AFB presently obtains its water supplies from a distribution system comprised of 29 water wells constructed along the east and west Base boundaries and by purchase from the Oklahoma City Water Department. All Base wells are finished into the Garber-Wellington aquifer. Base wells range from 700 to 900 feet in finished depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones with a combined thickness from 103 to 184 feet (Wickersham, 1979).

Although the variability in the geology and the recharge system at Tinker AFB makes it difficult to predict local flow paths, Central Oklahoma aquifer water table data show that regional groundwater flow under Tinker varies from west-northwest to southwest, depending on location. This theory is supported by contoured potentiometric data from base monitoring wells which show groundwater movement in the upper and lower aquifer zones to generally follow regional dip. Measured normal to potentiometric contours, groundwater flow gradients range from 0.0019 to 0.0057 ft/ft. However, because flow in the near-surface portions of the aquifer at Tinker AFB is strongly influenced by topography, local stream base-levels, complex subsurface geology, and location in a recharge area, both direction and magnitude of groundwater movement is highly variable. The interaction of these factors not only influences regional flow but gives rise to complicated local, often transient, flow patterns at individual sites.

As a result of ongoing environmental investigations and the approximately 450 groundwater monitoring wells installed on the Base during various investigations, a better understanding of the specific hydrological framework has emerged. The current conceptual model developed by Tinker AFB (Tinker, 1993), based on the increased understanding of the hydrological framework, has been revised from an earlier model adopted by the USACE. Previous studies reported that groundwater was divided into four water-bearing zones: the perched aquifer, the top of regional aquifer, the regional aquifer, and the producing zone. In the current model, two principal water table aquifer zones and a third less extensive zone have been identified. The third is limited to the southwest quadrant. The third aquifer zone consisted of saturated siltstone and thin sandstone beds in the Hennessey Shale and equates to the upper water bearing zone (UWBZ) described by the USACE (1993) at Landfills 1 through 4. In addition, numerous shallow, thin saturated beds of siltstone and sandstone exist throughout the Base. These are of limited areal extent and are often perched.

In the current conceptual hydrologic model, a USZ and an LSZ are recognized in the interval from ground surface to approximately 200 feet. Below this is found the producing zone from which the Base draws much of its water supply. Figure 3-4 shows the potentiometric surface for the USZ and Figure 3-5 shows the potentiometric surface for the LSZ. The USZ exists mainly under water table (unconfined) conditions, but may be partially confined locally. Conditions in the LSZ are difficult to determine due to screen placement and overly long sandpacks below the screen interval.



LEGEND

Potentiometric Contours Elevation above MSL

Approximate Direction of Groundwater Flow

Contours are extrapolated across center of base due to lack of data

FIGURE 3-4
TINKER AIR FORCE BASE
UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 23MAR94	DATE LAST REV.:	DRAFT. CHCK. BY:	INITIATOR: C.WALLACE	DWG. NO.:40983209C.
DRAWN BY: C.E.TUMLIN	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J.TAYLOR	PROJ. NO.:409832

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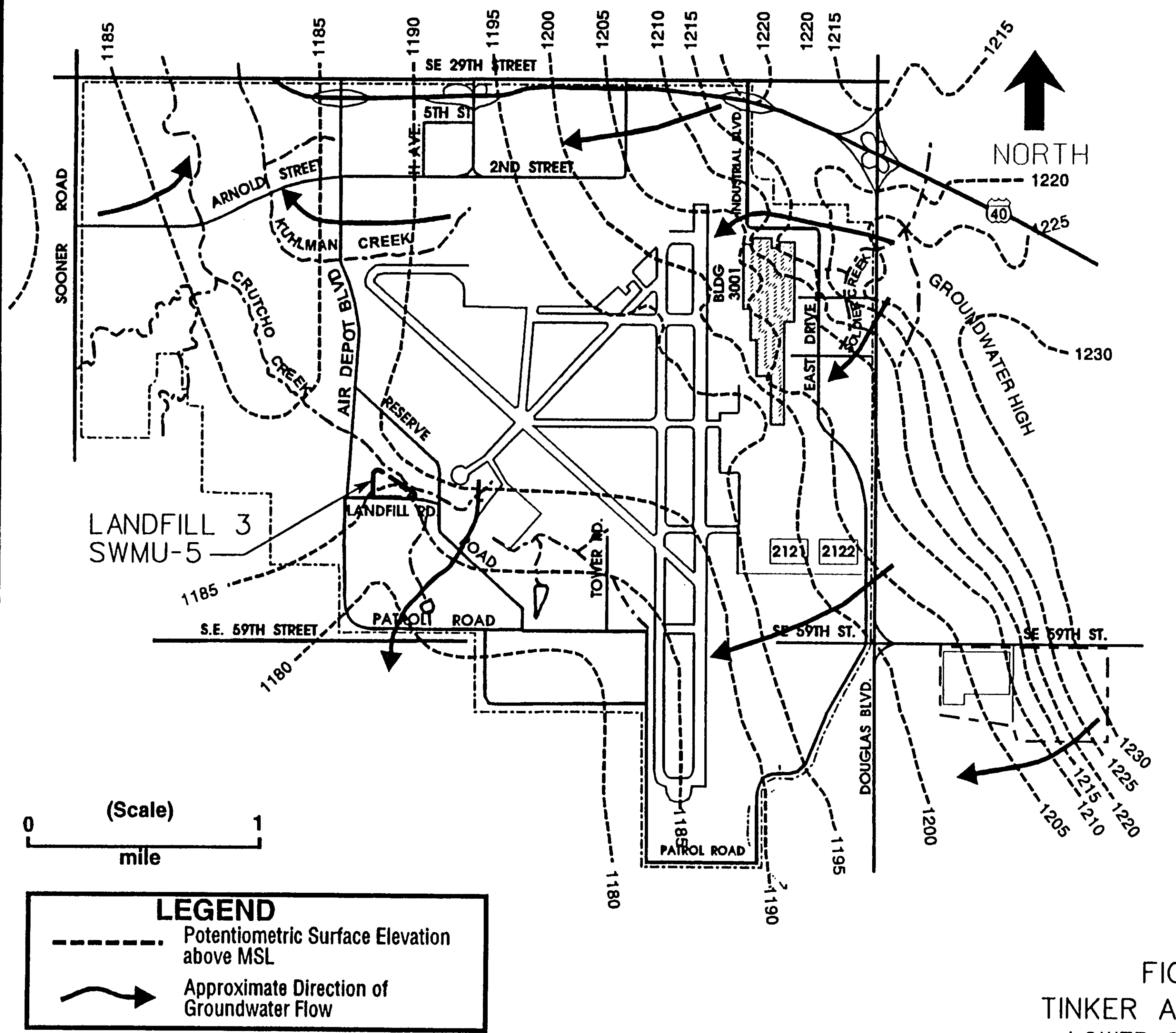

Contours are extrapolated across center of base due to lack of data

FIGURE 3-5
TINKER AIR FORCE BASE
LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 23MAR94	DATE LAST REV.:	DRAFT. CHCK. BY:	INITIATOR: C.WALLACE	DWG. NO.: 40983209C.
DRAWN BY: C.E.TUMLIN	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J.TAYLOR	PROJ. NO.: 409832

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The USZ is found at a depth of 5 to 70 feet below ground surface and has a saturated thickness ranging from less than 1 foot at its eastern boundary to over 20 feet in places west of Building 3001. The USZ is erosionally truncated by Soldier Creek along the northeastern margin of Tinker AFB. This aquifer zone is considered to be a perched aquifer over the eastern one-third of Tinker AFB, where it is separated from the LSZ by an underlying confining shale layer and a vadose zone. The confining interval extends across the entire Base, but the vadose zone exists over the eastern one-third of this area. The available hydrogeologic data indicate that the vadose zone does not exist west of a north-south line located approximately 500 to 1,000 feet west of the main runway; consequently, the USZ is not perched west of this line. However, based on potentiometric head data from wells screened above and below the confining shale layer, the USZ remains a discrete aquifer zone distinct from the LSZ even over the western part of the Base. In areas where several shales interfinger to form the lower confining interval rather than a single shale bed, "gaps" may occur. In general, these "gaps" are not holes in the shale, but are places where multiple shales exist that are separated by slightly more permeable strata. Hydrologic data from monitoring wells indicate that these zones allow increased downward flow of groundwater above what normally leaks through the confining layer.

The LSZ is hydraulically interconnected and can be considered one aquifer zone down to approximately 200 feet. This area includes what was referred to by the USACE (1993) as the top of regional and regional zones. Hydrogeologic data from wells screened at different depths at the same location within this zone, however, provide evidence that locally a significant vertical (downward) component of groundwater flow exists in conjunction with lateral flow. The magnitude of the vertical component is highly variable over the Base. Preliminary evidence suggests that the LSZ is hydraulically discrete from the producing zone. Due to variations in topography, the top of the lower zone is found at depths ranging from 50 to 100 feet below ground surface under the eastern parts of the Base and as shallow as 30 feet to the west. Differences in potentiometric head values found at successive depths are due to a vertical (downward) component of groundwater flow in addition to lateral flow and the presence or absence of shale layers which locally confine the aquifer system. The LSZ extends east of the Base (east of Soldier Creek) beyond the limits of the USZ where it becomes the first groundwater zone encountered in off-Base wells. Because of the regional dip of bedding, groundwater gradient, and topography, the LSZ just east of the Base is generally encountered at depths less than 20 feet.

3.3.2 Site Hydrology

The groundwater beneath Landfill 3 exists in three distinct zones: the Hennessey water bearing zone (HWBZ), USZ, and LSZ. The HWBZ is a perched water bearing zone developed in the southwest quadrant of Tinker AFB in the vicinity of Landfills 1 through 4. This zone is characterized by numerous thin saturated siltstone and sandstone beds alternating with shale beds. Delineating of this zone is complicated by a complex stratigraphy of water bearing and sealing beds of limited areal extent. Due to the complex stratigraphy and limited well control, the UWBZ and USZ are considered as a single zone for the purposes of this report.

The uppermost saturated zone is the USZ. This zone, which by definition includes the UWBZ, is hydraulically connected to the water encountered in the landfill trenches and Crutcho Creek. The USZ was previously identified in the RI report for Landfills 1 through 4 (USACE, 1993) as the perched zone. Figure 3-4 presents the potentiometric surface for the USZ in the Tinker AFB area. The figures shows that groundwater flow in the vicinity of Landfill 1 is generally to the southwest.

The deepest hydrogeologic zone at the site is the LSZ. The LSZ was previously identified in the RI report for Landfills 1 through 4 as the top of the regional zone. The LSZ is composed primarily of interbedded shale, siltstone, and sandstone. Figures presented in the RI report (USACE, 1993) depicting potentiometric surfaces for groundwater based on 1987 and 1990 monitoring well data show groundwater flowing in different directions. The 1987 contours show the LSZ flowing in a southeast direction; sufficient data to accurately predict localized groundwater flow in the vicinity of Landfill 3 has not been collected. The LSZ formation was encountered at depths of 50 to 70 feet below grade and extended to a maximum depth of 125 feet before encountering a lower confining unit. The permeability of the formation was measured to be 1.2×10^{-3} cm/s.

The USZ and the LSZ are separated by a low permeability shale layer. This shale interval, which is part of the Hennessey Group, varies in thickness and pinches out north of Landfill Road underneath Landfill 3. The shale interval acts as the lower confining bed for the USZ and, therefore, perches the USZ. This shale interval is the second mappable layer discussed earlier under the section on stratigraphic correlation. The landfill trenches are set within and underlain by clay. The clay is a low-permeability layer, but it does not present as much of a barrier as the shale layer to the south. Average permeabilities for the clay and shale layers were reported to be 1.4×10^{-8} cm/s and 3×10^{-9} cm/s, respectively.

The USZ is a sandstone layer across the site. Polyvinyl chloride (PVC) pipes set in the landfill trenches have water levels corresponding to the USZ. The USZ sandstone was encountered at a depth between 15 and 30 feet below grade and ranged in thickness from a few feet to as much as 25 feet. The USZ is underlain by a substantial layer of shale and siltstone ranging in thickness from 8 to 25 feet. Vertical migration of the USZ groundwater and contaminants occurs primarily by movement through preferential pathways in the formation under semiconfined and confined conditions, with the interbedded coarser-grained material acting as a conduit to the LSZ. The permeability of the USZ formation was measured to be 1.4 x 10^{-3} cm/s, and that of the underlying siltstone to be 3 x 10^{-8} cm/s.

3.4 Soils

Three major soil types have been mapped in the Tinker AFB area and are described in Table 3-2 (U.S. Department of Agriculture [USDA], 1969). The three soil types, the Darrell-Stephenville, Renfrow-Vernon-Bethany, and Dale-Canadian-Port, consist of sandy to fine sandy loam, silt loam, and clay loam, respectively. The Darrell-Stephenville and the Renfrow-Vernon-Bethany are primarily residual soils derived from the underlying shales of the Hennessey Group. The Dale-Canadian-Port association is predominantly a stream-deposited alluvial soil restricted to stream floodplains. The thickness of the soils ranges from 12 to 60 inches. Landfill 3 lies entirely within the Renfrow-Vernon-Bethany soil association.

Table 3-2

Tinker AFB Soil Associations
(Source: USDA, 1969)

Association	Description	Thickness (in.)	Unified Classification[a]	Permeability (in./hr)
Darrell-Stephenville: loamy soils of wooded uplands	Sandy loam Sandy clay loam Soft sandstone (Garber Sandstone)	12-54	SM,ML,SC	2.0-6.30
Renfrow-Vernon-Bethany: loamy and clayey soils on prairie uplands	Silt loam - clay Clay loam Shale (Fairmont Shale)	12-60	ML,CL,MH,CH	<0.60-0.20
Dale-Canadian-Port: loamy soil on low benches near large streams	Fine sandy loam Silty clay loam Loam Clay loam	12-60	SM,ML,CL	0.05-6.30

[a]Unified classifications defined in U.S. Bureau of Reclamation, 5005-86.

4.0 Source Characterization

Landfill 3 was used for the disposal of an estimated 180,000 yd^3 of general refuse generated by Tinker AFB from 1952 to 1961. Along with general refuse, industrial wastes such as paint buckets, insecticide cans, and barrels were also deposited in the landfill. Two specific-use dump areas are located within the boundaries of Landfill 3.

- A sludge dump, located in the south-central area of the landfill, was in use from 1961 to 1968. It is reported to contain waste oils and other liquids from industrial operations at Building 3001 and waste fuels and sludge from the POL Facility (USACE, 1989).

- An area reportedly containing lead-contaminated soils is located in the northern portion of the landfill (USACE, 1993). The suspected source of this contamination was not documented in the prior reports.

Landfill 3 occupies approximately 8.25 acres and is located in the southwest corner of Tinker AFB, just north of Landfill Road, bordering Crutcho Creek to the north and east, and Building 1022 to the west.

Landfill 3 was constructed by excavating a series of trenches oriented east to west across the site. Waste was deposited in the trenches and covered daily with several inches of excavated native soil. A final cover of 3 to 4 feet of soil was placed over the completed trench cells. A landfill cap, designed in accordance with EPA technical guidelines, was constructed in December 1991. The cap was designed to minimize the infiltration of precipitation, reduce soil erosion, and control stormwater runoff.

During the course of the remedial investigations by the USACE, 24 soil borings were drilled within the boundary of the landfill. Soil and waste samples were collected by three methods: split-spoon samplers, Shelby tubes, and composite samples. Geologic logs for the borings are contained in Appendices B and J of the USACE 1993 draft final RI report for Landfills 1 through 4. Table 4-1 contains the waste description and depth of occurrence for each boring advanced into Landfill 3. Waste materials were encountered in 23 of the 24 borings.

The soil/waste samples collected were analyzed for various contaminants. The samples collected were not all analyzed for the same array of chemical parameters. The following analytes were among the parameters tested: VOCs, SVOCs, TPH, pesticides, total metals,

Table 4-1

Waste
SWMU-5, Landfill 3, Tinker AFB

Boring No.	Waste Description	Depth (feet)
L3-1	Oily sludge, paper, plastic, rope	3.5-17.0
L3-2	Asphalt, cement, paper, plastic, black material	0.5-10.9
L3-2-1	Asphalt, black sludge mixed with clay	0.5-12.0
L3-2-2	Asphalt, black sludge mixed with clay	3.0-12.0
L3-2-3	Asphalt, brown clay (waste), solvent odor	2.0-11.0
L3-2-4	Asphalt, sludge, solvent odor	0.5-14.0
L3-2-5	Asphalt, solvent odor	1.0-14.0
L3-2-6	Asphalt, solvent odor	0.5-14.0
L3-2-7	Black sludge, hydrocarbon odor	9.0-14.0
L3-2-8	Asphalt, sludge, hydrocarbon odor	0.5-13.0
L3-2-9	Organic odor	2.5-13.0
L3-2-10	Asphalt, brown sludge, solvent odor	0.0-9.0
L3-2-11	Asphalt, sludge, solvent odor	1.0-13.0
L3-2-12	Asphalt, clay with brown streaks, solvent odor	1.0-7.0
L3-2-13	Asphalt, brown clay with solvent odor	1.0-9.0
L3-2-14	Asphalt	0.5-3.0
L3-3	Cement, asphalt, paper, glass, wire, black clayey material	4.5-18.0
L3-4	Oily black sludge, asphalt, concrete, burned trash, wire, unburned trash	2.0-18.0
L3-5	Paper, plastic, scrap metal, metal shavings, wire, black material	4.0-10.0
L3-7	Paper, plastic, scrap metal, metal shavings, wire, black material	4.0-10.0
L3-8	Wire, cable	0.0-5.5
L3-9	Asphalt, trash	0.0-12.5
L3-10	Asphalt	0.0-4.0
L3-11	Asphalt	2.0-3.0

Reference: U.S. Army Corps of Engineers (USACE), Draft Final RI Report, Landfills 1 through 4, October 1993.

TOC, cyanide, pH, conductivity, phenols, EP toxicity metals, and PCBs. VOCs, SVOCs, metals, and PCBs were detected in Landfill 3 soils.

Some of the boreholes were equipped so that leachate and groundwater samples could be collected for analysis. Water samples were extracted from the trench water, the perched groundwater, and the top of regional groundwater. The trench water samples were found to be highly contaminated. Contaminant concentrations in groundwater from monitoring wells, screened in the perched and top of regional aquifers, were several orders of magnitude below those found in the trench water samples. The nature and extent of soil and groundwater contamination is discussed in Chapter 5.0, Contaminant Characterization.

5.0 Contaminant Characterization

Through several phases of investigation, soils and groundwater have been sampled for contaminants potentially introduced into the environment as a result of past waste disposal practices at Landfill 3. Analytical results of samples taken in and around Landfill 3 indicate the presence of metals, as well as VOCs, SVOCs, and PCBs at concentrations that exceed some action levels. Action levels used for comparison in order of priority include maximum contaminant levels (MCL), SWMU corrective action levels (CAL), and water quality standards (WQS). Contaminants have been detected in the soils and groundwater in the former disposal trenches, and some contamination has been detected in groundwater outside the former trench areas.

Soils. During RI activities performed by the USACE under the IRP (USACE, 1993), 21 samples were obtained from 25 soil borings drilled into Landfill 3. Soil samples were collected during three separate investigations in 1987, 1989, and 1990. Constituents analyzed for during the soil investigations included VOCs, SVOCs, metals, pesticides, PCBs, EP toxicity metals, phenols, TPH, TOC, cyanide, pH, and conductivity. VOCs, SVOCs, metals, and PCBs were detected in Landfill 3 soils. Summaries of chemical data from the soil investigations are provided in Tables 5-1, 5-2, and 5-3.

Establishment of Surficial Soil Background Concentrations. Background soil concentrations for trace metals (Table 5-4) were determined based on a study performed by the USGS (1991). The study area was confined to approximately four counties in central Oklahoma. Tinker AFB lies at the approximate center of this area. A total of 293 B-horizon soil samples were collected throughout this area. Soil samples were collected at the top of the B-horizon, which was usually 20 to 30 centimeters below the surface but ranged from 3 to 50 centimeters below the surface. For site-specific analytes for which the USGS offered no background value, the analyte was compared to an applicable action level.

The use of B-horizon soil as selected by the USGS for metals background concentrations in soil is conservative in that the soil sampled does not reflect all possible anthropogenic influences. Most of the samples were obtained from hill crests and well drained areas in pasture and forested land, well away from roadways to minimize contamination from vehicular emissions (i.e., nearly "pristine" areas). Trace metal inputs to the study site soils on Base, however, will come from anthropogenic sources outside of the study area, in addition to those sources related to disposal activities or operations within the confines of the study site.

Table 5-1

Summary of Analytical Results - 1987 Soil Investigation SWMU-5, Landfill 3, Tinker AFB

(Page 1 of 2)

Boring No. Depth (ft) Sample No. Sample Date	L3-1 3.5-17 7-162 2/87	L3-2-A 0.5-11 7-121 1/87	L3-2-A 2-11 7-159 1/87	L3-3 16.5-22 7-163 2/87	L3-4 2-8.5 1-122 1/87	L3-4 2-18 7-160 1/87	L3-4 8.5-18 1-123 1/87	L3-5 4-10 7-161 1/87
Volatiles (µg/kg)								
Acetone	<13	NT	3900	<14	NT	<1800	NT	<1650
Benzene	<7	NT	490J	7J	NT	<900	NT	<825
2-Butanone	<13	NT	8900	<14	NT	<1800	NT	<1650
Chlorobenzene	8	NT	3200	210	NT	<900	NT	<825
2-Chloroethyl vinyl ether	<13	NT	9200	<14	NT	<1800	NT	<1650
1,2-Dichloroethane	<7	NT	680J	<7	NT	<900	NT	<825
Trans-1,2-dichloroethene	<7	NT	370000	<7	NT	<900	NT	<825
Ethyl benzene	10	NT	5000	12	NT	<900	NT	<825
2-Hexanone	<13	NT	13000	<14	NT	<1800	NT	<1650
Methylene chloride	8	NT	8300	33	NT	<1900	NT	<825
4-Methyl-2-pentanone	13J	NT	7600	14J	NT	<1800	NT	<1650
Styrene	<7	NT	<725	8	NT	<900	NT	<825
Tetrachloroethene	<7	NT	430000	<7	NT	<900	NT	<825
Toluene	7J	NT	170000	7J	NT	<900	NT	<825
Vinyl acetate	<7	NT	1000J	<7	NT	<900	NT	<825
1,1,1-Trichloroethane	<7	NT	980	<7	NT	<900	NT	<825
Trichloroethene	<7	NT	3000000	<7	NT	640J	NT	<825
Xylenes (total)	23	NT	17000	27	NT	<900	NT	<825
Semivolatiles (µg/kg)								
Bis(2-ethylhexyl)phthalate	<13200	NT	120000	<14500	NT	3700J	NT	<13000
Chrysene	<13200	NT	23000	<14500	NT	<14000	NT	<13000
1,2-Dichlorobenzene	<13200	NT	210000	<14500	NT	<14000	NT	<13000
1,4-Dichlorobenzene	<13200	NT	40000	<14500	NT	<14000	NT	<13000
2-4-Dimethylphenol	<13200	NT	31000	<14500	NT	<14000	NT	<13000
Fluoranthene	<13200	NT	17000J	<14500	NT	<14000	NT	<13000
4-Methylphenol	<13200	NT	43000	<14500	NT	<14000	NT	<13000
1,2,4-Trichlorobenzene	<13200	NT	24000	<14500	NT	<14000	NT	<13000

Table 5-1

(Page 2 of 2)

Boring No. Depth (ft) Sample No. Sample Date	L3-1 3.5-17 7-162 2/87	L3-2-A 0.5-11 7-121 1/87	L3-2-A 2-11 7-159 1/87	L3-3 16.5-22 7-163 2/87	L3-4 2-8.5 1-122 1/87	L3-4 2-18 7-160 1/87	L3-4 8.5-18 1-123 1/87	L3-5 4-10 7-161 1/87
Metals (mg/kg)								
Arsenic	<1.0	1.1	1.4	<1.0	<1.0	<1.0	<1	<0.1
Barium	380	330	330	710	290	310	170	530
Cadmium	12	27	200	51	2.5	29	93	47
Chromium	140	270	380	48	7.0	42	42	12
Lead	480	550	130	1100	20	150	250	51
Mercury	0.5	<0.1	<0.1	0.97	<0.1	0.51	0.68	<0.1
Nickel	15	54	43	29	14	30	73	16
Silver	2	1.8	2.4	2.2	1.4	2.1	0.87	0.74
Zinc	530	780	57	610	20	2100	2000	130
Indicators (mg/kg)								
TOC	2700	29000	20000	23000	8500	24000	3000	9000
Cyanide	<0.2	1.6	2.3	1.2	<0.2	<0.2	<0.2	0.9
pH (s.u.)	7.54	6.89	7.17	6.93	7.34	7.35	7.06	7.16
Conductivity (μmhos/cm)	700	1400	1400	1200	700	700	900	600
Phenols (μg/kg)	1100	660000	NT	NT	350	NT	550	NT

NT - Compound not tested for
B - Compound also present in blank
J - Compound present below laboratory detection limits
E - Concentration exceeded laboratory equipment calibration limits

Table 5-2

Summary of Analytical Results - 1988 Sludge Dump Investigation SWMU-5, Landfill 3, Tinker AFB

Boring No. Depth (ft) Sample No. Sample Date	3-2-B 5.0 TK3-2B 3/88	3-2-B 9.5 TK3-2B 3/88	3-2-6 12.5 8-594 5/88	3-2-7 1.0 8-595 5/88	3-2-10 12.0 8-596 5/88	3-2-12 8.0 8-597 5/88	3-2-13 7.0 8-598 5/88	3-2-14 10.0 8-599 5/88
Volatiles (μg/kg)								
Acetone	<50	<12500	2700B	200	2100B	<11	50B	44B
2-Butanone	<50	<12500	10000	<100	6600	<11	<11	11J
Trans-1,2-dichloroethene	100	232240	5600	130	2500	200	<6	2200E
Ethyl benzene	<25	19280	610	71	230J	<6	<6	0.4 J
Methylene chloride	96	84740	300	23J	<280	<6	1J	2J
4-Methyl-2-pentanone	<50	117320	3800	280	2100	<11	<11	<11
Tetrachloroethene	<25	446900	28000	<52	3600	<6	<6	4J
Toluene	<25	226200	8400B	1300	1400B	2J	5B J	38 B
Trichloroethene	778	4070000	350000E	1500	18600	7	9	11
Vinyl chloride	<50	<12500	<570	<100	<560	<11	<11	6J
Xylenes (total)	<25	131000	2700	250	1100	<6	3J	7
Semivolatiles (μg/kg)								
1,2-Dichlorobenzene	NT	NT	57000	1800	3800	5J	6J	7J
1,3-Dichlrobenzene	NT	NT	1400	210	74J	<11	<11	<11
1,4-Dichlorobenzene	NT	NT	<570	<100	<560	<11	<11	3J
Metals (mg/kg)								
Barium	496	<100	NT	NT	NT	NT	NT	NT
Cadmium	120	2.4	NT	NT	NT	NT	NT	NT
Chromium	384	8.0	NT	NT	NT	NT	NT	NT
Lead	5031	28	NT	NT	NT	NT	NT	NT
Zinc	325	13.4	NT	NT	NT	NT	NT	NT
Indicators (mg/kg)								
TPH	3760	7450	851	17100	266	60.3	74.9	175

NT - Compound not tested for
B - Compound also present in blank
J - Compound present below laboratory detection limits
E - Concentration exceeded laboratory equipment calibration limits

Table 5-3

Summary of Analytical Results - 1990 Soil Investigation
SWMU-5, Landfill 3, Tinker AFB

Boring No. Depth (ft) Sample No. Sample Date	L3-9 7-8 0-1366 5/90	L3-9 11-12 0-1367 5/90	L3-10 7-8 0-1368 5/90
Volatiles (µg/kg)			
Benzene	<5	13.2	<50
Ethyl benzene	<5	26.1	443
Tetrachloroethene	<5	<5	39500
Toluene	<5	14.2	20000
Trichloroethene	<5	<5	75900
Semivolatiles (µg/kg)			
Bis(2-ethylhexyl)phthalate	<660	24000	2600
1,4-Dichlorobenzene	<5	<19800	2500
Naphthalene	<660	<19800	910
Aroclor-1254	<100	<100	2600

Table 5-4

Background Concentrations of Trace Metals in Surface Soils[a] SWMU5, Landfill 3, Tinker AFB

(Page 1 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Concentration in %			
Aluminum	0.005	0.38	8.9
Cadmium	0.005	0.01	9.4
Iron	0.005	0.18	5.8
Magnesium	0.005	0.02	5.3
Phosphorous	0.005	0.06	0.019
Potassium	0.05	0.1	2.4
Sodium	0.005	0.02	0.99
Titanium	0.005	0.04	0.42
Concentrations in ppm			
Arsenic	0.1	0.6	21
Barium	1	47	6400
Beryllium	1	<1	3
Bismuth	10	<DL[b]	<DL
Cadmium	2	<DL	<DL
Cerium	4	14	110
Chromium	1	5	110
Cobalt	1	<1	27
Copper	1	<1	59
Europium	2	---[c]	---
Gallium	4	<4	23
Gold	8	<DL	<DL
Holmium	4	<DL	<DL
Lanthanum	2	7	51
Lead	4	<4	27

Table 5-4

(Page 2 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Lithium	2	5	100
Manganese	10	24	3400
Molybdenum	2	<DL	<DL
Neodymium	4	6	47
Nickel	2	<2	61
Niobium	4	<4	16
Scandium	2	<2	15
Selenium	0.1	<0.1	1.2
Silver	2	<DL	<DL
Strontium	2	13	300
Tantalum	40	<DL	<DL
Thorium	1	<1.40	15.00
Tin	10	<DL	<DL
Uranium	0.1	0.650	6.400
Vanadium	2	5	220
Ytterbium	1	<1	3
Yttrium	2	3	43
Zinc	2	3	79

[a]All B-horizon soil samples (293) from USGS, 1991.
[b]All concentrations below the lower limits of determination.
[c]Insufficient or no data.

Therefore, responsibility may be taken for more trace metal impacts than are actually attributable to a given site.

An additional level of conservatism was added in the manner in which the site-specific metals concentrations were compared to the background levels. Typically, the environmental concentrations of trace metals at study sites are represented by the arithmetic upper 95^{th} confidence interval on the mean of a normal distribution. This upper 95^{th} confidence interval value is then compared to the background values. The intent of this typical approach is to estimate a Reasonable Maximum Exposure case (i.e., well above the average case) that is still within the range of possible exposures.

To expedite this comparison and establish greater conservatism, the maximum concentration found at the site of concern, rather than the upper 95^{th} confidence interval value, was compared to the USGS background values. If the environmental concentration of a particular analyte was below or within the minimum-maximum range of the USGS background concentrations, that analyte was considered to be naturally occurring and of no further concern to this investigation. Given the conservative approach of the comparisons, site-specific metals concentrations would have to significantly exceed the USGS background levels and be attributable to operations at the site before they would be considered a contaminant of concern.

The numerical comparison of site-specific metals concentrations to the USGS background concentrations is presented in the following section.

Groundwater. Groundwater in the vicinity of Landfill 3 was investigated by sampling groundwater in soil borings within the landfill and selected groundwater monitoring wells adjacent to the landfill. Groundwater from eight soil borings were sampled to characterize the contamination within the USZ in the vicinity of the former landfill trenches (borings L3-3, L3-4, and L3-5), the sludge dump (borings L3-2-A, L3-7, L3-9, and L3-11), and the lead-contaminated area (boring L3-1). Table 5-5 presents a summary of the data from these sampling efforts.

Monitoring wells 2A, 3A, 4A, and 76A were used to monitor the groundwater adjacent to the landfill in the USZ. Monitoring wells 4B and 76B monitored groundwater adjacent to the

Table 5-5

Summary of Analytical Results
1986 - 1990 Trench Water Sampling
SWMU-5, Landfill 3, Tinker AFB

(Page 1 of 4)

Boring Number	L3-1	L3-2-A	L3-3	L3-3	L3-4	L3-4	L3-5	L3-5	L3-7	L3-9	L3-11
Sample Number	6-330	7-288	7-283	0-2012	7-284	0-2013	7-287	0-2014	0-2016	0-2017	0-2015
Sample Date	05/86	3/87	3/87	6/90	3/87	6/90	3/87	6/90	6/90	6/90	6/90
Volatiles (µg/L)											
Acetone	260 J	74000	<100	NT	15	NT	9 J	NT	10	<10	NT
Benzene	NA	<10000	71	39.8	61	9.5	15	8.3	<5	8	<5
2-Butanone	12000	180000	<100	NT	<10	NT	<10	NT	<10	<10	NT
Chlorobenzene	<500	<1000	940	918	59	6.8	77	40.7	<5	<5	<5
Ethyl benzene	NA	<10000	<50	5.3	<5	<5	<5	<5	<5	3 J	<5
Trans-1,2-dichloroethene	180 J	240000	<50	<5	<5	<5	<5	<5	<5[a]	<5[a]	<5
2-Hexanone	<1000	32000	<100	NT	<10	NT	<10	NT	<10	<10	NT
Methylene chloride	<500	9700 J	<50	<10	<5	<10	<5	<10	5 B	3 BJ	<10
4-Methyl-2-pentanone	NA	<20000	<100	NT	14	NT	<10	NT	<10	<10	NT
Styrene	NA	<10000	<50	NT	5	NT	<5	NT	<5	<5	NT
Toluene	<500	5300 J	120	<5	3 J	<5	<5	<5	<5	2 J	<5
Trichloroethene	<500	120000	<50	104	<5	<5	<5	<5	<5	<5	12.2
Vinyl acetate	NA	<20000	<100	NT	6 J	NT	<10	NT	<10	<10	NT
Vinyl chloride	<1000	5100 J	<100	<10	<10	<10	<10	<10	<10	16	<10
Xylenes	NA	<10000	<50	33.7	<5	6.6	<5	<5	<5	9	<5

KN/1256/SWMU5/SWMU5.5-5/04-07-94/D8 4:25pm

Table 5-5

(Page 2 of 4)

Boring Number	L3-1	L3-2-A	L3-3	L3-3	L3-4	L3-4	L3-5	L3-5	L3-7	L3-9	L3-11
Sample Number	6-330	7-288	7-283	0-2012	7-284	0-2013	7-287	0-2014	0-2016	0-2017	0-2015
Sample Date	05/86	3/87	3/87	6/90	3/87	6/90	3/87	6/90	6/90	6/90	6/90
Semivolatiles (µg/L)											
Arochlor-1254	NA	<16000	<400	12	<400	<1	<400	<1	<1	<1	<1
Arochlor-1260	NA	<16000	<400	<1	<400	<1	<400	3.5	<1	<1	<1
Benzoic acid	NA	<4000	<100	NT	<100	NT	<100	NT	<50	12 J	NT
Bis(2-ethylhexyl)phthalate	3 J	3900	93	77	20 J	120	<20	74	13	6 J	35
1,2-Dichlorobenzene	NA	30000	4 J	<10	<20	<10	<20	<10	<10	1 J	<10
1,3-Dichlorobenzene	NA	<800	6J	<10	<20	<10	<20	<10	<10	<10	<10
1,4-Dichlorobenzene	<10	5400	29	20	20 J	<10	4 J	<10	<10	2 J	<10
Diethyl phthalate	20	<800	20	<10	<20	15	97	70	<10	2 J	<10
2,4-Dimethylphenol	40	18000	52	24	<20	<10	13 J	<10	<10	<10	<10
Di-n-butyl phthalate	NA	<800	<20	<10	<20	<10	<20	<10	<10	4 J	<10
Di-n-octyl phthalate	<10	<800	9 J	<10	<20	<10	<20	<10	<10	<10	<10
2-Methylna phthalene	NA	820	4 J	NT	<20	NT	5 J	NT	<10	6 J	NT
2-Methylphenol	NA	17000	<20	<10	<20	<10	<20	<10	<10	<10	<10
4-Methylphenol	<10	73000	57	NT	<20	NT	6 J	NT	<10	18	NT
Napththalene	6 J	790 J	38	31	20 J	<10	15 J	10	<10	25	<10
N-nitrosodiphenylamine	NA	<800	8 J	<10	<20	<10	<20	<10	<10	<10	<10
Phenanthrene	NA	150 J	<20	NT	<20	NT	<20	NT	<10	0.9 J	<10
Phenol	<10	15000	<20	<10	<20	<10	<20	<10	<10	<10	<10
1,2,4-Trichlorobenzene	NA	14000	<20	<10	<20	<10	<20	<10	<10	<10	<10

KN/1256/SWMU5/SWMU5.5-5/04-07-94/D8 4:25pm

Table 5-5

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Boring Number	L3-1	L3-2-A	L3-3	L3-3	L3-4	L3-4	L3-5	L3-5	L3-7	L3-9	L3-11
Sample Number	6-330	7-288	7-283	0-2012	7-284	0-2013	7-287	0-2014	0-2016	0-2017	0-2015
Sample Date	05/86	3/87	3/87	6/90	3/87	6/90	3/87	6/90	6/90	6/90	6/90
Metals (µg/L)											
Arsenic	4.8	36	6.1	NT	8.3	NT	3.5	NT	NT	NT	NT
Barium	2700	2500	7300	NT	<500	NT	3200	NT	NT	NT	NT
Cadmium	<7.5	28	33	NT	7.5	NT	10	NT	NT	NT	NT
Chromium	10	28	60	NT	18	NT	1600	NT	NT	NT	NT
Iron	NT	10000	120000	NT	11000	NT	110000	NT	NT	NT	NT
Lead	50	460	670	NT	78	NT	820	NT	NT	NT	NT
Manganese	NT	4700	1300	NT	1000	NT	3000	NT	NT	NT	NT
Mercury	<0.1	<0.1	1.3	NT	<0.1	NT	3.1	NT	NT	NT	NT
Nickel	28	170	170	NT	35	NT	48	NT	NT	NT	NT
Zinc	48	500	310	NT	95	NT	880	NT	NT	NT	NT
Radiometrics											
Gross alpha (pCi/L)	80±27	<2	<2	NT	<2	NT	<2	NT	NT	NT	NT
Gross beta (pCi/L)	53±17	27±12	80±15	NT	22±12	NT	10±6	NT	NT	NT	NT
Total radium (pCi/L)	<1	<1	11±4	NT	<1	NT	4±3	NT	NT	NT	NT
Indicators (mg/L)											
pH (s.u.)	6.69	6.55	6.11	NT	6.70	NT	5.97	NT	7.08	6.49	6.99
Conductivity (µmhos/cm)	2.24	99.9	1031	NT	1255	NT	988	NT	NT	NT	NT
TOC	49	4300	50	NT	27	NT	16	NT	NT	NT	NT

KN/1256/SWMU5/SWMU5.5-5/04-07-94/D8 4:25pm

Table 5-5

(Page 4 of 4)

Boring Number	L3-1	L3-2-A	L3-3	L3-3	L3-4	L3-4	L3-5	L3-5	L3-7	L3-9	L3-11
Sample Number	6-330	7-288	7-283	0-2012	7-284	0-2013	7-287	0-2014	0-2016	0-2017	0-2015
Sample Date	05/86	3/87	3/87	6/90	3/87	6/90	3/87	6/90	6/90	6/90	6/90
Indicators (mg/L) (Continued)											
Oil and grease	<1	550	3.2	NT	3.6	NT	<1.0	NT	NT	NT	NT
Chloride	52	450	380	NT	35	NT	7.5	NT	NT	NT	NT
Sulfate	19	13	180	NT	270	NT	220	NT	NT	NT	NT
Cyanide	<0.2	<0.2	<0.2	NT	<1.0	NT	<0.2	NT	NT	NT	NT

[a]Analysis for 1,2-dichloroethene (total).
B = Compound also found in blank.
J = Compound present below laboratory detection limits.
NT = Compound not tested for.
NA = Data not available.

landfill in the LSZ. A summary of the analytical results from the 1986 through 1992 groundwater monitoring efforts is presented in Table 5-6 for the USZ and Table 5-7 for the LSZ.

5.1 Constituents of Potential Concern

The analytical results of soil and groundwater samples from Landfill 3 are available from past IRP investigation activities. Evaluation of these analytical results for the purpose of identifying constituents of potential concern with respect to both human health and the ecological impacts has not been performed. However, an interpretation has been made comparing the analytical results to active levels established in Chapter 7.0 of this document. The following sections summarize these interpretations.

5.2 Soil Characterization

During the RI, the USACE (1993) assessed the magnitude and extent of contamination originating from historical landfill disposal practices. Initially, five soil borings (L3-1 L3-2-A, L3-3, L3-4, and L3-5) were advanced into areas of suspected contamination at Landfill 3 in 1987. The results of the soil investigations are discussed in the following sections.

5.2.1 Lead-Contaminated Area

Boring L3-1 was advanced in an area identified during early investigations as potentially contaminated with lead. The location of this boring is shown in Figure 3-3 in the RI report (USACE, 1993). A summary of the analytical results from this sample are presented in Table 5-1. Low levels of chlorobenzene, ethyl benzene, methylene chloride, 4-methyl-2-pentanone, toluene, and xylenes were detected. Total xylenes had the highest concentration at 23 micrograms per kilogram (μg/kg). Two metals, lead and zinc, were detected at concentrations exceeding the USGS Background Values for these contaminants. Lead was the most significantly elevated above background at 480 milligrams per kilogram (mg/kg), almost 18 times the USGS background value for lead of 27 mg/kg. Zinc, which was detected at 530 mg/kg, was nearly 7 times its USGS background value of 79 mg/kg.

5.2.2 Landfill Trenches

Borings L3-3, L3-4, and L3-5 were drilled into the former landfill trenches. The locations of these borings are shown in Figure 3-3 in the RI report (USACE, 1993). A summary of the contaminant data for samples collected from these borings is presented in Table 5-1. The samples were analyzed for VOCs, SVOCs, metals, pesticides, cyanide, and indicators such as pH, TOC, and specific conductance. The analytical data indicate that some organic contami-

Table 5-6

Summary of 1986-1992 Analytical Results
Upper Saturated Zone Monitoring Wells
SWMU-5, Landfill 3, Tinker AFB

(Page 1 of 8)

Well Number	2A[a]					3A[a]				
Sample Number	6-330	8-1045	9-1121	0-2088	921202 - LF11-2	6-333	8-1141	9-1170	0-2090	921202 - LF13-3A
Sample Date	05-01-86	08-08-88	08-17-89	06-26-90	12-02-92	05-01-86	08-16-88	08-27-89	06-26-90	12-02-92
Volatiles (µg/L)										
Acetone	<10	<10	<10	NT	NT	<10	<10	<10	NT	NT
Benzene	<5	<5	<5	0.6	0.6	NA	<5	<5	<5	77
Benzoic acid	<50	<48	<50	NT	NT	NA	<49	<52	NT	NT
2-Butanone	<10	<10	<10	NT	NT	<10	<10	<10	NT	NT
Chlorobenzene	<5	<5	<5	<5	7	<5	<5	<5	<5	2
1,1-Dichloroethane	<5	<5	<5	<5	<0.5	NA	<5	<5	<5	0.8
1,2-Dichloroethane	<5	<5	<5	<5	0.6	NA	<5	<5	<5	<0.5
1,1-Dichloroethene	<5	<5	<5	<5	<0.5	NA	<5	<5	<5	6
Cis-1,2-dichloroethene	NT	8[b]	11[b]	NT	8	NA	NT	NT	NT	6
Trans-1,2-dichloroethene	12	8[b]	11[b]	<5	0.6	<5	<5	<5	<5	<0.5
Ethyl benzene	<5	<5	<5	<5	<0.5	NA	<5	<5	<5	3
Methylene chloride	<5	<5	<5	<10	16B	<5	<5	<5	<10	<0.6
Tetrachloroethene	<5	<5	<5	<5	<0.5	NA	<5	<5	<5	4
Toluene	<5	1 J	<5	<5	0.8	<5	<5	<5	<10	1

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Table 5-6

(Page 2 of 8)

Well Number	2A[a]					3A[a]				
Sample Number	6-330	8-1045	9-1121	0-2088	921202 - LF11-2	6-333	8-1141	9-1170	0-2090	921202 - LF13-3A
Sample Date	05-01-86	08-08-88	08-17-89	06-26-90	12-02-92	05-01-86	08-16-88	08-27-89	06-26-90	12-02-92
Volatiles (µg/L) (Continued)										
1,1,1-Trichloroethane	<5	<5	<5	<5	<0.5	NA	<5	<5	<5	1
Trichloroethene	<5	0.6 J	<5	<5	2	<5	<5	<5	<5	18
Vinyl chloride	<10	<10	<10	<10	5	<10	<10	<10	<10	<0.5
Xylenes, total	<5	<5	<5	<5	<0.5	<5	<5	<5	<5	<0.5
Semivolatiles (µg/L)										
Bis(2-ethylhexyl)phthalate	75	<10	14	41	2 J	<10	4 J	2 J	24	<10
1,2-Dichlorobenzene	<10	<10	<10	<5	1	NA	<10	<11	<10	<0.5
1,4-Dichlorobenzene	<10	<10	<10	<10	0.6	<10	<10	<11	<5	<0.5
2,4-Dimethylphenol	<10	<10	<10	19	<10	<10	<10	19	<10	<11
Di-n-butyl pthalate	<10	<10	<10	<10	<10	NA	<10	<10	<10	<11
Isopropylbenzene	NT	NT	NT	NT	<0.5	NA	NT	NT	NT	1
Naphthalene	<10	<10	<10	<10	3 B	NA	<10	<11	<10	2 B
Dimethyl phthalate	<10	<10	<10	<10	380	NA	<10	<11	<10	77
Di-n-octyl phthalate	<10	<10	22	17	<10	<10	3 J	3 J	10	<11
Phenol	<10	<10	8 J	<10	<10	NA	<10	<10	<10	<11

Table 5-6

(Page 3 of 8)

Well Number	2A[a]					3A[a]				
Sample Number	6-330	8-1045	9-1121	0-2088	921202 - LF11-2	6-333	8-1141	9-1170	0-2090	921202 - LF13-3A
Sample Date	05-01-86	08-08-88	08-17-89	06-26-90	12-02-92	05-01-86	08-16-88	08-27-89	06-26-90	12-02-92
Metals (µg/L)										
Arsenic	17	46	21	10.5	15	4.4	3.7	3.5	4	3
Barium	2700	2800	3200	168	2860	2800	2000	2100	176	2080
Cadmium	10	<5	<5	<10	<5	10	<5	<5	<10	<5
Chromium	<10	<5	5	<10	<7	<10	12	6	<10	<7
Iron	NT	NT	1000	92.1	NT	NT	NT	1100	527	NT
Lead	53	21	22	<20	<42	38	18	<10	<20	<42
Manganese	NT	NT	610	54.8	NT	NT	NT	960	173	NT
Mercury	<0.1	<0.1	0.12	<0.2	<0.2	<0.1	0.4	0.83	<0.2	<0.2
Nickel	240	NT	NT	NT	15.8	140	NT	NT	NT	<15
Selenium	<0.4	<0.4	<0.4	<1	<2	<0.4	<0.4	<0.4	<1	<2
Silver	13	<5	<5	<10	<7	<10	<5	<5	<10	<7
Zinc	190	NT	NT	NT	NT	93	NT	NT	NT	NT
Radiometrics (pCi/L)										
Gross alpha	<2	NT	3.86±12.4	3±2	NT	8±5	NT	0±5.83	4±3	NT
Gross beta	<3	NT	2.35±9.12	7±3	NT	13±5	NT	8.66±5.01	6±3	NT
Total radium	NT	NT	0.45±0.19	2±1	NT	NT	NT	0.18±0.11	2±1	NT

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Table 5-6

Well Number	2A[a]					3A[a]				
Sample Number	6-330	8-1045	9-1121	0-2088	921202 - LF11-2	6-333	8-1141	9-1170	0-2090	921202 - LF13-3A
Sample Date	05-01-86	08-08-88	08-17-89	06-26-90	12-02-92	05-01-86	08-16-88	08-27-89	06-26-90	12-02-92
Indicators (mg/L)										
pH (s.u.)	7.33	7.38	7.25	7.02	NT	6.98	NT	6.67	6.82	NT
Chloride	137.5	220	210	178	NT	70	32	56	47.8	NT
Sulfate	3	6.4	1.2	<2	NT	3	6.1	5	3.52	NT
Oil and grease	<1	NT	<1	<5	NT	NT	NT	<1	<5	NT
TDS	NT	NT	NT	NT	952	NT	NT	NT	NT	600
TOC	7.5	5.2	9.51	1.37	10.6	6.7	8.2	7.69	0.781	3.2
Conductivity (μmhos/cm)	1729	1760	1240	1721	NT	1565	NT	970	1335	NT

Table 5-6

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Well Number	4A[a]					76Aa		
Sample Number	6-334	8-1182	9-1175	0-2092	921111 - LF13-4	8-1248	9-1233	0-2097
Sample Date	05-01-86	08-18-88	08-28-89	06-26-90	11-11-92	08-22-88	08-31-89	06-26-90
Volatiles (µg/L)								
Acetone	46	<10	<10	NT	NT	<10	<10	NT
Benzene	<5	<5	<5	<5	0.4J	NA	<5	<5
Benzoic acid	<50	3J	<50	NT	NT	NA	<50	NT
2-Butanone	27	<10	<10	NT	NT	<10	<10	NT
Chlorobenzene	23	61	49	23.8	16	5	8	6.4
1,1-Dichloroethane	<5	<5	<5	<5	<0.5	NA	<5	<5
1,2-Dichloroethane	<5	<5	<5	<5	<0.5	NA	<5	<5
1,1-Dichloroethene	<5	<5	<5	<5	<0.5	NA	<5	<5
Cis-1,2 dichloroethene	NT	NT	NT	NT	0.5	NA	NT	NT
Trans-1,2-dichloroethene	<5	<5	<5	<5	<0.5	<5	14[b]	<5
Ethyl benzene	<5	<5	<5	<5	0.4J	NA	<5	<5
Methylene chloride	<5	<5	<5	<10	0.4JB	<5	<5	<10
Tetrachloroethene	<5	<5	<5	<5	0.6	NA	<5	<5
Toluene	3J	<5	<5	<10	0.8	<5	<5	<5
1,1,1-Trichloroethane	<5	<5	<5	<5	<0.5	NA	<5	<5
Trichloroethene	<5	<5	<5	<5	13	1J	<5	<5

Table 5-6

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Well Number	4A[a]					76Aa		
Sample Number	6-334	8-1182	9-1175	0-2092	921111 - LF13-4	8-1248	9-1233	0-2097
Sample Date	05-01-86	08-18-88	08-28-89	06-26-90	11-11-92	08-22-88	08-31-89	06-26-90
Volatiles (µg/L) (Continued)								
Vinyl chloride	<10	<10	<10	<10	<0.5	<10	20	<10
Xylenes, total	<5	<5	<5	<5	0.5J	NA	<5	<5
Semivolatiles (µg/L)								
Bis(2-ethylhexyl)phthalate	<10	<10	1J	12	1J	<10	<10	<10
1,2-Dichlorobenzene	<10	<10	<10	<10	1	NA	<10	<10
1,4-Dichlorobenzene	<10	<10	2J	<5	1	<10	<10	5.7
2,4-Dimethylphenol	<10	<10	<10	<10	<9	<10	<10	<10
Di-n-butyl phthalate	<10	<10	0.3J	<10	<9	<10	<10	<10
Isopropylbenzene	NT	NT	NT	NT	0.4J	NA	NT	NT
Naphthalene	<10	<10	<10	<10	2B	NA	<10	<10
Dimethyl phthalate	<10	<10	<10	<10	58	NA	<10	<10
Di-n-octyl phthalate	<10	<10	<10	<10	<9	<10	<10	<10
Phenol	<10	<10	<10	<10	<9	NA	<10	<10
Metals (µg/L)								
Arsenic	9.8	4.5	3.2	3.8	3.3	<1	1.1	1.2
Barium	2900	1300	1100	55.9	1050	1100	930	53.6
Cadmium	10	<5	<5	<10	<5	<5	<5	<10

Table 5-6

(Page 7 of 8)

Well Number	4A[a]					76Aa		
Sample Number	6-334	8-1182	9-1175	0-2092	921111 - LF13-4	8-1248	9-1233	0-2097
Sample Date	05-01-86	08-18-88	08-28-89	06-26-90	11-11-92	08-22-88	08-31-89	06-26-90
Metals (µg/L) (Continued)								
Chromium	25	12	6.8	<10	<7	10	8.8	<10
Iron	NT	NT	480	156	NT	NT	0.07	<10
Lead	35	18	<10	<20	<42	22	12	<20
Manganese	NT	NT	1000	139	NT	NT	3300	532
Mercury	<0.1	<0.1	<0.1	<0.2	<0.2	0.24	<0.1	<0.2
Nickel	320	NT	NT	NT	<15	NT	NT	NT
Selenium	<0.4	1.5	<0.4	<1	<2	0.9	NT	<1.0
Silver	<10	<5	<5	<10	<7	<5	<5	<10
Zinc	950	NT	NT	NT	NT	NT	NT	NT
Radiometrics (pCi/L)								
Gross alpha	<2	NT	0.2±3	4±3	NT	NT	24.7±8.13	3±2
Gross beta	<3	NT	0±7.2	5±3	NT	NT	14.2±5.97	6±3
Total radium	NT	NT	0.06±0.08	<1	NT	NT	0±0.16	<1
Indicators (mg/L)								
pH (s.u.)	6.94	8.14	6.66	6.48	NT	6.59	6.81	6.92
Chloride	137.5	180	190	112	NT	190	172	133
Sulfate	8	7.2	12	<2	NT	9.8	8.8	10.9

Table 5-6

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Well Number	4A[a]					76Aa		
Sample Number	6-334	8-1182	9-1175	0-2092	921111 - LF13-4	8-1248	9-1233	0-2097
Sample Date	05-01-86	08-18-88	08-28-89	06-26-90	11-11-92	08-22-88	08-31-89	06-26-90
Indicators (mg/L) (Continued)								
Oil and grease	2.6	NT	<1	<5	NT	NT	<1	<5
TDS	NT	NT	NT	NT	864	NT	NT	NT
TOC	19	13	16	1.97	9.7	21	12	3.37
Conductivity (μmhos/cm)	1918	625	1230	1685	NT	2180	1490	1738

[a]No data available for 1987 and 1991 for monitoring wells 2A, 3A, and 4A. No data available for 1986, 1987, 1991, and 1992 for monitoring well 76A.
[b]Analysis for 1,2-dichloroethene (total).
NA = Data not available.
NT = Compound not tested for.
B = Compound also found in blank.
J = Compound present below laboratory detection limit.

Table 5-7

Summary of 1987-1992 Analytical Results
Lower Saturated Zone Monitoring Wells
SWMU-5, Tinker AFB

(Page 1 of 3)

Well Number	4B[a]					76B[b]		
Sample Number	7-188	8-1170	9-1627	0-2093	921111 - LF13-4B	8-1470	9-1234	0-2098
Sample Date	02-14-87	08-16-88	09-22-89	06-26-90	11-11-92	09-27-88	08-31-89	06-26-90
Volatiles (µg/L)								
Acetone	65	<10	<10	NT	NA	<10	<10	NT
2-Butanone	11	<10	<10	NT	NA	<10	<10	NT
Chlorobenzene	<5	<5	<5	NA	0.2 J	NA	<5	NA
Methylene chloride	<5	<5	3 J	<10	0.5 JB	<5	6	<10
Trichloroethene	<5	1 J	<5	<5	0.7	<5	<5	<5
Semivolatiles (µg/L)								
Bis(2-ethylhexyl)pthalate	<10	9 J	22	11	<10	8 J	<10	<10
1,2-Dichlorobenzene	<10	<10	<10	<10	0.3 J	<10	<10	<10
1,4-Dichlorobenzene	<10	<10	<10	<10	0.2 J	<10	<10	<10
Dimethyl phthalate	<10	<10	<10	<10	22	<10	3 J	<10
Isopropylbenzene	NT	NT	NT	NT	0.1 J	NA	NT	NA
Naphthalene	<10	<10	<10	NA	2B	NA	<10	NA
Di-n-octyl phthalate	<10	<10	<10	<10	<10	<10	2 J	<10
Phenol	210	14	<10	<10	<10	<10	<10	<10

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Table 5-7

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Well Number	4B[a]					76B[b]		
Sample Number	7-188	8-1170	9-1627	0-2093	921111 - LF13-4B	8-1470	9-1234	0-2098
Sample Date	02-14-87	08-16-88	09-22-89	06-26-90	11-11-92	09-27-88	08-31-89	06-26-90
Metals (µg/L)								
Arsenic	<1	1.2	1.6	2.3	<2	1.8	5	2.1
Barium	1600	940	690	85.8	637	680	440	23.2
Chromium	<10	11	<5	<10	<7	<5	9.8	<10
Iron	38	NT	120	1790	NT	NT	90	120
Lead	45	14	<10	<20	<42	10	<10	<20
Manganese	<10	NT	18	85.4	NT	NT	11	<5
Mercury	<0.1	0.12	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2
Nickel	28	NT	NT	NT	<15	NT	NT	NT
Selenium	<0.4	1.7	<0.4	<1	<2	0.6	<0.4	<1
Zinc	20	NT	NT	NT	NT	NT	NT	NT
Radiometrics (pCi/L)								
Gross alpha	<2	NT	2±6	6±4	NT	NT	0±4.11	6±4
Gross beta	22±4	NT	5±0	21±6	NT	NT	6±4.39	11±6
Total radium	<1	NT	0.1±0.1	7±2	NT	NT	0.14±0.17	2±1
Indicators (mg/L)								
pH (s.u.)	12.47	8.16	9.96	10.18	NT	7.39	7.84	7.74
Chloride	13	11	33	25.7	NT	13	17	5.37

Table 5-7

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Well Number	4B[a]					76B[b]		
Sample Number	7-188	8-1170	9-1627	0-2093	921111 - LF13-4B	8-1470	9-1234	0-2098
Sample Date	02-14-87	08-16-88	09-22-89	06-26-90	11-11-92	09-27-88	08-31-89	06-26-90
Sulfate	14	4.4	2.4	3.59	NT	6.5	3.8	6.08
Oil and grease	<1	NT	<0.2	<5	NT	NT	<1	11
Indicators (mg/L) (Continued)								
TDS	NT	NT	NT	NT	338	NA	NT	NA
TOC	9.4	0.72	1.09	<0.5	<1	<0.1	0.9	<0.5
Conductivity (μmhos/cm)	4250	545	240	294	NT	698	4000	715

[a]No data available for monitoring well 4B for 1986 and 1991.
[b]No data available for monitoring well 76B for 1986, 1987, 1991, and 1992.
B = Compound also found in blank.
J = Compound present below laboratory detection limits.
NT = Compound not tested for.
NA = Data not available.

contamination was detected in borings L3-3 and L3-4. The organic compounds with the highest concentrations were bis(2-ethylhexyl)phthalate at 3,700J µg/kg (L3-4), trichloroethene at 6,40J µg/kg (L3-4), and chlorobenzene at 210 µg/kg (L3-3). No organic contamination was detected at boring L3-5. No pesticides or PCBs were detected in any of these borings. All three borings exhibited concentrations of zinc and lead above USGS average background.

5.2.3 Sludge Dump

Boring L3-2-A was drilled in the former sludge dump area in 1987. The analytical results of the two samples collected from this boring are presented in Table 5-1. The samples collected at this location revealed elevated levels of industrial solvents and petroleum products. Seventeen VOCs and 12 SVOCs were detected in the samples. The organic compounds detected at the highest concentrations were trichloroethene (3,000,000 µg/kg), tetrachloroethene (430,000 µg/kg), trans-1,2-dichloroethene (370,000 µg/kg), 1,2-dichlorobenzene (210,000 µg/kg), toluene (170,000 µg/kg), and bis(2-ethylhexyl)phthalate (120,000 µg/kg). An organic layer 10 to 12 inches thick was discovered floating on top of the groundwater in borehole L3-2-A. A free product was analyzed and determined to most closely resemble JP-4, although it was found to contain other hydrocarbon fuels. Eight metals were detected in soils above average MCLs: arsenic, barium, cadmium, chromium, lead, nickel, silver, and zinc. Of the eight metals, cadmium, chromium, nickel, and zinc were detected at concentrations more than one order of magnitude above average background.

Because of the elevated levels of contaminants discovered in this boring, a follow-up investigation was conducted in 1988 to define the horizontal and vertical extent of the organic contamination at the sludge dump. Fifteen additional soil borings were then advanced in this area. The locations of these borings are shown in Figure 2 in Appendix B of the RI report (USACE, 1993). The soil samples collected from these boreholes were analyzed for TPH, VOCs, SVOCs, pesticides, total metals, TOC, cyanide, pH, conductivity, and phenols. The data from this follow-up investigation are presented for samples L3-2-B through L3-2-14 in Table 5-2. The analytical results indicated the soils in the sludge dump area were contaminated with elevated concentrations of 14 VOCs, 3 SVOCs, and 5 metals. The organic compounds detected at the highest concentrations were trichloroethene (4,070,000 µg/kg), tetrachloroethene (446,900 µg/kg), trans-1,2-dichloroethene (232,240 µg/kg), toluene (226,200 µg/kg), and xylenes (131,000 µg/kg). Cadmium, chromium, lead, and zinc were the metals most significantly elevated above MCLs. Soil at borehole L3-2-B was also analyzed for EP toxicity metals. The results of the EP toxicity test on soils from borehole L3-2-B were below regulated levels. The study concluded that the soil was contaminated with petroleum hydrocarbons and solvents to a depth of 12 feet.

The concentrations of organic contaminants were significantly higher at the sludge dump than the other areas of investigation at Landfill 3. The maximum concentration for 33 of the 34 organic compounds detected in soils at the landfill originated from the sludge dump samples. The organic compounds most frequently detected were toluene, trichloroethene, xylenes, ethyl benzene, trans-1,2-dichloroethene, methylene chloride, and 1,2-dichlorobenzene. The organic compounds with the highest detected concentrations were trichloroethene, 1,2-dichlorobenzene, tetrachloroethene, trans-1,2-dichloroethene, toluene, xylenes, bis(2-ethylhexyl)phthalate, and 4-methyl-2-pentanone. Cadmium, chromium, lead, and zinc were detected at concentrations significantly above average USGS background levels.

An on-site, full-scale test of a low-temperature thermal treatment system was conducted in 1989 to demonstrate removal of VOC and SVOC contamination from sludge dump soils. Approximately 3,000 yd^3 of contaminated soil was excavated from the sludge dump area. PCBs were subsequently discovered in the feed and processed soils and the test was discontinued. Additional soil sampling was conducted in 1990 as part of a site exit plan to determine the magnitude of PCB contamination in the excavated soil. The analytical results of this investigation are presented in Figure B-1 in Appendix B of the decontamination certification report (Weston, 1990b). Aroclor-1260 was the only PCB detected in this round of sampling. The concentration of Aroclor-1260 ranged from 24 to 270 mg/kg in excavated soils, and as much as 5,900 mg/kg in pit sludge samples. The excavated soils were returned to the excavation site and covered with a 2-foot-thick clay cap.

After the thermal treatment equipment was decontaminated and removed from the site, and the excavated soils replaced, a follow-up investigation was conducted in and around the sludge dump area to define the extent of the PCB contamination remaining after the discontinued thermal treatment test. Five borings (L3-7, L3-8, L3-9, L3-10, and L3-11) were advanced in this area in May 1990. Three samples collected from borings L3-9 and L3-10 were analyzed for VOCs, SVOCs, and PCBs. The analytical results from these samples are presented in Table 5-3. Elevated concentrations of Aroclor 1254, tetrachloroethene, toluene, trichloroethene, bis(2-ethylhexyl)phthalate, and 1,4-dichlorobenzene were detected in the samples. Aroclor-1254 was detected in boring L3-10 at 2,600 μg/kg, 29 times greater than the SWMU CAL value for this analyte.

5.3 Groundwater Characterization

The quality of the groundwater within the landfill trenches and the surrounding aquifer is discussed in the following sections.

5.3.1 Landfill Trench Water

The landfill trenches and specific-use dump sites at Landfill 3 were constructed within the USZ groundwater. Table 5-5 presents a summary of the analytical data collected during groundwater investigations at the landfill in 1987 and 1990. The data represent the quality of trench water in the vicinity of the landfill trenches, the sludge dump, and the lead-contaminated area. Groundwater quality for each of these areas is discussed separately in the following sections.

5.3.1.1 Lead-Contaminated Area

The data from boring L3-1 in Table 5-5 represents the quality of groundwater in contact with lead-contaminated soils. Three VOCs and four SVOCs were detected in the groundwater at this boring: acetone, 2-butanone, trans-1,2-dichloroethene, bis(2-ethylhexyl)phthalate, diethyl phthalate, 2,4-dimethylphenol, and naphthalene. The organic compound detected at the highest concentration was 2-butanone (12,000 micrograms per liter [μg/L]).

Barium and lead were the only metals detected above MCLs. Lead was detected at 50 μg/L. The MCL for lead is currently 15 μg/L.

The radiometric measurements for groundwater from boring L3-1 were among the highest detected in any Landfill 3 borings. The highest gross alpha measurement was detected in trench water from boring L3-1 (80 plus or minus 27 picocuries per liter [pCi/L]).

5.3.1.2 Landfill Trenches

Groundwater samples taken from borings L3-3 through L3-5 represent the quality of groundwater impacted by disposal of refuse in trenches at Landfill 3 from 1952 to 1961. The results of the 1987 and 1990 sampling efforts are presented in Table 5-5. Ten VOCs, 11 SVOCs, 2 PCBs, and 10 metals were detected in the samples. Organic compounds with the most significantly elevated concentrations were: chlorobenzene (940 μg/L), bis(2-ethylhexyl)-phthalate (120 μg/L), toluene (120 μg/L), trichloroethene (104 μg/L), and benzene (71 μg/L). The PCBs Aroclor-1254 and Aroclor-1260 were detected at 12 μg/L and 3.5 μg/L.

The following metals were detected above MCLs: arsenic, barium, cadmium, chromium, lead, mercury, nickel, and zinc. The maximum concentration for 8 of 10 metals detected in the USZ within the boundaries of Landfill 3 originated from borings L3-3 and L3-5.

The indicator parameter cyanide was detected at a concentration above the MCL for this contaminant.

A comparison of the 1987 and 1990 analytical data for organic compounds shows that the 1990 results are, in general, slightly lower than the 1987 results.

5.3.1.3 Sludge Dump

Boring L3-2-A in Table 5-5 represents the quality of trench groundwater in contact with sludge dump wastes. Although a layer of free product was discovered when the first water sample was collected from boring L3-2-A, no organic phase was encountered in future sampling at this boring or during sampling at any of the remaining boreholes at the sludge dump. The sample from boring L3-2-A contained the most contaminated groundwater detected at the landfill. Eight VOCs and 11 SVOCs were detected, with trans-1,2-dichloroethene exhibiting the highest concentration at 240,000 μg/L. Other organic compounds detected at elevated levels included 2-butanone at 180,000 μg/L, trichloroethene at 120,000 μg/L, acetone at 74,000 μg/L, and 4-methylphenol at 73,000 μg/L. The maximum concentration for 22 of the 34 organic compounds detected in Landfill 3 trench groundwater originated from sludge dump borehole L3-2-A.

Barium, cadmium, lead, nickel, and zinc were detected above MCL concentrations.

In 1990, groundwater samples were collected from borings L3-7, L3-9, and L3-11. These borings were outside the sludge dump area, but were sampled to determine the extent of contamination remaining after the discontinued low-temperature thermal extraction study conducted by USATHAMA at the sludge dump. The samples were analyzed for VOCs, SVOCs, and PCBs. Seven VOCs and ten SVOCs were detected, but at levels significantly below the concentrations found in groundwater at sludge dump boring L-2-A. Organic compounds with the highest concentrations included bis(2-ethylhexyl)phthalate (35 μg/L), naphthalene (25 μg/L), 4-methylphenol (18 μg/L), vinyl chloride (16 μg/L), xylenes (9 μg/L), and benzene (8 μg/L).

5.3.2 USZ Groundwater

The extent of USZ groundwater contamination at Landfill 3 was further evaluated by analyzing groundwater data for monitoring wells 2A, 3A, 4A, and 76A. The locations of these monitoring wells are shown on Drawings 6 and 8 in the RI report (USACE, 1993). These wells were sampled during the RI and selected wells continue to be sampled as part of the ongoing groundwater monitoring program for the site. The available analytical data for these wells for 1986 through 1992 are presented in Table 5-6.

Eighteen VOCs and ten SVOCs were detected in USZ groundwater. The organic compounds detected at the highest concentration were: dimethyl phthalate (380 µg/L), bis(2-ethylhexyl)-phthalate (75 µg/L), chlorobenzene (61 µg/L), acetone (46 µg/L), 2-butanone (27 µg/L), di-n-octyl phthalate (22 µg/L), and vinyl chloride (20 µg/L). A comparison of the data in Tables 5-5 and 5-6 for organics shows that fewer groundwater contaminants were detected in the monitoring wells in comparison to the trench borings, and the concentration of organics in the monitoring wells are typically several orders of magnitude lower than those in the trench water.

Barium, cadmium, lead, manganese, and nickel, were detected at levels above MCLs. The concentrations of chromium, iron, and lead in monitoring wells were significantly below the concentrations of those constituents in groundwater samples collected from borings within the landfill boundaries.

During the RI, isoconcentration contours of selected contaminants were mapped for USZ groundwater. Plumes of trichloroethene, trans-1,2-dichloroethene, barium, gross alpha, gross beta, and total radium are presented in drawings 14, 15, 16, 17, 18, 19, and 20 of the RI report (USACE, 1993).

The highest concentrations of trichloroethene and trans-1,2-dichloroethene are located at the Landfill 3 sludge dump. These plumes originate at the sludge dump and flow radially away from this area with the greatest horizontal component of contaminant migration to the southwest, toward Landfill 4.

A barium plume of 1,000 µg/L is widespread in the USZ underneath Landfill 3, with the exception of an area of low concentration at the southwest corner of the landfill in the vicinity of boring L3-4.

The gross alpha plume originates in the vicinity of boring L3-1, with a maximum concentration of 80 pCi/L at this location. The greatest lateral component of contaminant migration follows groundwater flow to the northwest towards Landfill 1, and to the southwest towards the northwest corner of Landfill 4.

The gross beta plume appears to originate in the vicinity of borings L3-1 and L3-3, with the greatest horizontal component of migration following groundwater flow to the northwest and southwest, similar to the gross alpha plume.

The highest concentrations of total radium were detected at boring L3-3 and at monitoring well 1B northwest of Landfill 1. These two sampling points lie along a line that intersects the location of Radioactive Waste Disposal Site (RWDS)-1022E, SWMU-22, but boring L3-3 is upgradient of RWDS-1022E. The largest lateral component of total radium migration appears to be to the northwest, following the path of groundwater in this area.

5.3.3 LSZ Groundwater

The quality of LSZ groundwater in the vicinity of Landfill 3 can be evaluated by analyzing groundwater data for monitoring wells 4B and 76B. The locations of these wells are shown on Drawings 9 and 10 in the RI report (USACE, 1993). These wells were sampled during the RI and selected wells continue to be sampled as part of the ongoing groundwater monitoring program for the site. The available analytical data for these wells from 1986 to 1992 is presented in Table 5-7.

Five VOCs and eight SVOCs were detected in LSZ groundwater. Organic compounds detected at the highest concentrations included: phenol (210 μg/L), acetone (65 μg/L), bis(2-ethylhexyl)phthalate (22 μg/L), and dimethyl phthalate (22 μg/L). A comparison of the data in Tables 5-5 and 5-7 shows that 62 percent fewer organic compounds were detected in the LSZ monitoring wells than in groundwater from landfill borings. Also, the concentration of organics in the LSZ monitoring wells are typically several orders of magnitude lower than those in groundwater from the landfill borings. In addition, a comparison of the groundwater data for USZ and LSZ monitoring wells in Tables 5-6 and 5-7 shows that fewer organic compounds were detected in LSZ monitoring wells. The concentrations of those organics detected in both wells were consistently lower in the LSZ wells. The only exceptions to this trend were acetone and phenol.

Lead was detected at levels above MCLs. All metals in groundwater from LSZ monitoring wells were significantly below those in landfill borings, and were also less than the comparable USZ concentrations, with the exception of iron and selenium.

One sample from monitoring well 4B showed elevated levels for total radium. None of the other radiological parameters were detected at significant levels.

6.0 Potential Receptors

A preliminary draft baseline risk assessment report (USACE, 1991) for Landfills 1 through 4 was issued by USACE in February 1991. The purpose of the risk assessment was to quantify the potential health risks to human receptors at the four sites. The risk assessment was prepared in accordance with EPA guidance documents current at the time. An assessment of site risks to ecological receptors was not included in the report.

The risk assessment treated Landfills 1 through 4 as one site. Therefore, the risks associated with Landfill 3 alone cannot be abstracted from the report. The following is a discussion of the potential receptors identified by the preliminary draft baseline risk assessment report.

6.1 Exposure Assessment Results/Human Receptors

An exposure assessment was performed to determine the potential human receptors and analyzed the potential exposure pathways at Landfills 1 through 4. Potentially exposed human populations were limited to industrial workers associated with Base operations for the following reasons:

- No completed exposure pathway exists now or in the foreseeable future which would potentially expose individuals outside the boundaries of Tinker AFB.
- Access to Tinker AFB is restricted to military personnel, civilian employees, and individuals such as retirees who are authorized to use Base facilities.
- Military housing on Tinker AFB is limited and is not in the vicinity of the Landfills 1 through 4 sites.

No sensitive subpopulations were identified within the industrial site workers determined to represent the potentially exposed population at the sites.

The land use at and near the Base is not expected to change because the facilities have decades of useful life remaining and the Base has an important and continuing mission. Conversion of nearby land to residential use is improbable because of noise and safety concerns associated with such land use around an active airport.

The covered waste trenches are the source of contamination at Landfill 3. Potential groundwater contamination via migration of landfill leachate was not identified as a significant transport mechanism. It was determined that contamination of useable groundwater was not possible because of the great horizontal and vertical distances to groundwater use points, and the natural geophysical impediments to contaminant movement in the area. All homes in the area around and downgradient of Landfills 1 through 4 are served by municipal water. Therefore, the potential exposure route involving ingestion of contaminated groundwater was determined to be incomplete for current and future scenarios.

The only complete exposure pathways identified during the exposure assessment are inhalation of contaminated soil particles and inhalation of organic vapors from contaminated soil.

A summary of the exposure pathways evaluated for potential receptors under current and future land use scenarios, and the rationale for inclusion or exclusion in the risk characterization is presented in Table 6-1.

6.2 Ecological Receptors

Tinker AFB lies within a grassland ecosystem, which is typically composed of grasses, forbes, and riparian (i.e., trees, shrubs, and vines associated with water courses) vegetation. This ecosystem has generally experienced fragmentation and disturbances as result of urbanization and industrialization at and near the Base. While no threatened or endangered plant species occur on the Base, the Oklahoma penstemon (*Penstemon oklahomensis*), identified as a rare plant under the Oklahoma Natural Heritage Inventory Program, thrives in several locations on Base. Tinker AFB policy considers rare species as if they were threatened or endangered and provides the same level of protection for these species.

In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base. However, one specie found on the Base, the Texas horned lizard (*Phrynosoma cornutum*), is a Federal Category 2 candidate specie and under review for consideration to be listed as threatened or endangered. Air Force policy (AFR 126-1) considers candidate species as threatened or endangered and provides the same level of protection.

The Oklahoma Department of Wildlife Conservation also lists several species within the state as Species of Special Concern. Information on these species suggests declining populations

Table 6-1

Summary of Complete Exposure Pathways
SWMUs 3-6, Landfills 1-4, Tinker AFB

Potentially Exposed Population	Exposure Route, Medium and Exposure Point	Pathways Selected for Evaluation?	Reason for Selection or Exclusion
Current Land Use			
Residents	Ingestion of groundwater from local wells downgradient.	No	Pathway is incomplete. All water is from municipal systems in areas downgradient from site.
Residents	Inhalation of contaminated particulates.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Inhalation of organic vapors.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Dermal contact with contaminated particulates.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Incidental ingestion of contaminated particles.	No	General public does not have access to facility or site. Pathway is incomplete.
Industrial workers	Inhalation of contaminated particles.	Yes	Workers will be present intermittently in adjacent facilities.
Industrial workers	Inhalation of organic vapors.	Yes	Workers will be present intermittently in adjacent facilities.
Industrial workers	Dermal contact with contaminated particles.	No	Workers will not be present on the site. Pathway is incomplete.
Industrial workers	Incidental ingestion of contaminated particles.	No	Workers will not be present on the site. Pathway is incomplete.
Future Land Use			
It is anticipated that there will be no long-term change in land use because the site is located on a defense installation that has a critical, continuing mission			

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but information is inadequate to support listing, and additional monitoring of populations is needed to determine the species status. These species also receive protection by Tinker AFB as threatened or endangered species. Of these species, the Swainson's hawk (*Buteo swainsoni*) and the burrowing owl (*Athene cunicularia*) have been sighted on Tinker AFB. The Swainson hawk, a summer visitor and prairie/meadow inhabitant has been encountered Basewide. The burrowing owl has been known to inhabit the Air Field at the Base.

7.0 Action Levels

An "action level" is defined by EPA in proposed rule 40 CFR 264.521 (55 FR 30798; 7/27/90), "Corrective Action for Solid Waste Management Units (SWMU) at Hazardous Waste Management Facilities," as a health- and environment-based level, determined by EPA to be an indicator for protection of human health and the environment. In the preamble to this proposed rule, the focus of the RFI phase is defined as "characterizing the actual environmental problems at the facilities." As part of this characterization, a comparison of the contaminant concentrations to certain action levels should be made to determine if a significant release of hazardous constituents has occurred. This comparison is then used to determine if further action or corrective measures are required for a SWMU or an AOC. The preamble to the proposed rule states that the concept of action levels was introduced because of the need for "a trigger that will indicate the need for a Corrective Measures Study (CMS) and below which a CMS would not ordinarily be required" (55 FR 30798; 7/27/90). If constituent concentrations exceed certain action levels at a SWMU or an AOC, further action or a CMS may be warranted; if constituent concentrations are below action levels, a finding of no further action may be warranted. This chapter of the report presents the initial analytical data as compared to certain potential action levels.

Action levels are concentrations of contaminants at or below which exposure to humans or the environment should not produce acute or chronic effects.

The action level information is presented in this chapter so that a constituent concentration at a sample location can be compared with its potential action level. Only constituents identified in the analysis are listed in the SWMU-5, Landfill 3 table. Table 7-1 shows the action levels for soil, water, and air as published in federal or state regulations, policies, guidance documents, or proposed rules.

The action levels listed in Table 7-1 are:

- ***SWMU Corrective Action Levels (CAL)*** - The first set of action levels provided in the table are those taken from the proposed rule (40 CFR 264.521) and provided as Appendix A to the rule as "Examples of Concentrations Meeting Criteria for Action Levels." These levels are health-risk based and are provided

Table 7-1

Action Levels
SWMU-5, Landfill 3, Tinker AFB

(Page 1 of 3)

Parameters	SWMU CAL[a]			MCL[b]	USGS[c] Background	NAAQS[d]	WQS[e]
	Soil (mg/kg)	Water (mg/L)	Air (µg/m³)	Water (mg/L)	Soil (mg/kg)	Air (µg/m³)	Water (mg/L)
Volatile Organics							
1,1-Dichloroethene	10		0.03	0.007			
1,1,1-Trichloroethane	7000	3.0	1000	0.2			173.1
1,2-Dichloroethane	8.0		0.04	0.005			
Acetone	8000	4.0					
Benzene				0.005			0.714
Carbon disulfide	8000	4.0					
Chlorobenzene	2000	0.7	20	0.1			
Cis-1,2-dichloroethene	8		0.04	0.07			
Ethyl benzene	8000	4.0		0.7			28.72
Methylene chloride	90	0.005	0.3	0.005			
Styrene	20,000	7.0		0.1			
Tetrachloroethene	10	0.0007	1.0	0.005			
Toluene	20,000	10	7000	1.0			301.9
Trans-1,2-dichloroethene	8		0.04	0.1			
Trichloroethene	60			0.005			
Vinyl chloride				0.002			
Xylenes (total)	2.0×10^5	70	1000	10			
Semivolatile Organics							
1,2-Dichlorobenzene				0.6			
1,3-Dichlorobenzene				0.6			
1,4-Dichlorobenzene				0.075			
1,2,4-Trichlorobenzene	2000	0.7	10	0.07			
Aroclor-1254	0.09	5.0×10^{-6}		0.002			7.9×10^{-7}

Table 7-1

(Page 2 of 3)

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air ($\mu g/m^3$)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air ($\mu g/m^3$)	WQS[e] Water (mg/L)
Semivolatile Organics (Continued)							
Aroclor-1260	0.09	5.0×10^{-6}		0.002			7.9×10^{-7}
Bis(2-ethylhexyl)phthalate	50	0.003		0.006			
Chrysene				0.0002			
Di-n-butyl phthalate	8000	4.0					
N-nitrosodiphenylamine	100	0.007					
Phenol	50,000	20					461.5
Metals							
Arsenic	80		7.0×10^{-5}	0.05	21		0.0014
Barium	4000		0.4	2	6400		
Cadmium	40		0.0006	0.005			0.0084
Chromium VI	400		9.0×10^{-5}				
Chromium				0.1	110		3.365
Lead				0.015[f]	27	1.5[g]	0.025
Mercury	20			0.002			0.0006
Nickel	2000	0.7		0.1	61		4.583
Selenium				0.05	1.2		
Silver	200						64.6
Zinc					79		

Table 7-1

(Page 3 of 3)

Parameters	SWMU CAL[a] Soil (mg/kg)	SWMU CAL[a] Water (mg/L)	SWMU CAL[a] Air ($\mu g/m^3$)	MCL[b] Water (mg/L)	USGS[c] Background Soil (mg/kg)	NAAQS[d] Air ($\mu g/m^3$)	WQS[e] Water (mg/L)
Radiometrics							
Gross Alpha				15 pCi/L			

[a]CAL - Corrective Action Levels
[b]MCL - Maximum Contaminant Levels
[c]USGS - United States Geological Survey
[d]NAAQS - National Ambient Air Quality Standards
[e]WQS - Water Quality Standards
[f]Action Level at the Tap
[g]3-month Average

as specific examples of levels below which corrective action would not be required.

- ***Maximum Contaminant Levels (MCL) -*** These values are provided from 40 CFR Subpart G, Sections 141.60 through 0.63 as promulgated under the Safe Drinking Water Act. These levels are designated for water media only.

- ***USGS Background -*** These values are provided from the USGS report titled "Elemental Composition of Surficial Materials from Central Oklahoma" (USGS, 1991). These values represent the levels of metals which naturally occur in Central Oklahoma soils.

- ***Background -*** These levels are provided where background could be determined. Where available, background concentrations are listed for metals in soil samples taken on site, which were thought to be unaffected by releases from a unit.

- ***National Ambient Air Quality Standards (NAAQS) -*** These standards are published in 40 CFR Part 50 under the Clean Air Act and apply to point sources that emit a limited number of constituents to the air. The constituents regulated are nitrogen dioxide, sulphur dioxide, carbon monoxide, lead, ozone, and particulate matter. Currently, it is assumed that none of the SWMUs or AOCs emit these compounds in regulated quantities and no air samples have been taken which would allow for a valid comparison.

- ***Water Quality Standards (WQS) -*** The WQS are the standards for surface water quality as established by the State of Oklahoma. These standards apply to point source discharges to surface waters and have been listed for those units adjacent to surface water.

8.0 Summary and Conclusions

Landfill 3 occupies approximately 8.25 acres and is located in the southwest corner of Tinker AFB. The landfill is just north of Landfill Road, bordering Crutcho Creek to the north and east, and Building 1022 to the west. Approximately 180,000 yd^3 of waste materials are estimated to have been deposited in the landfill between 1952 to 1961. The landfill was used primarily for the disposal of general refuse generated on base, but the wastes also included paint buckets, insecticide cans, and barrels. The waste was placed in trenches running east-west across the site and covered daily with several inches of excavated native soil. Two specific-use dump areas are located within the boundaries of Landfill 3.

- A sludge dump, located in the south-central area of the landfill, was in use from 1961 to 1968. This dump is reported to contain waste oils and other liquids from industrial operations at Building 3001 and waste fuels and sludge from the POL Facility (USACE, 1989).

- An area reportedly containing lead contaminated soils is located in the northern portion of the landfill (USACE, 1993).

The USACE conducted a RI of Landfills 1 through 4 from 1986 to 1990. During the investigations at Landfill 3, 25 borings were advanced into the soil and samples were collected for analysis. Three borings were placed in the former landfill trenches, one boring was placed in the lead contaminated area, 16 borings were placed in the vicinity of the sludge dump, and five borings were advanced into the landfill to determine the extent of contamination remaining after the low-temperature thermal treatment test at the sludge dump was discontinued.

The analytical results of the soils samples collected at the landfill revealed the following:

- The sludge dump is the most highly contaminated area within the landfill. It has been characterized with three sampling events summarized in Tables 5-1 through 5-3. In total 20 VOCs, 11 SVOCs, 1 pesticide/PCB, and 9 metals have been detected at the sludge dump. Three organic and four inorganic compounds were detected at concentrations that exceeded either the SWMU CAL or USGS background value for that analyte.

- The presence of lead in soil at levels significantly above MCLs was confirmed at the lead-contaminated area. Lead was detected at 480 mg/kg.

- Lower levels of organic contamination were discovered in two of the three boreholes advanced in the former landfill trenches. No organic compounds were detected in boring L3-5. Eight metals (barium, cadmium, chromium, lead, mercury, and zinc) were detected at elevated concentrations. The highest concentrations of metals were detected at borehole L3-3.

The quality of USZ and LSZ groundwater in the vicinity of the landfill was evaluated during the RI. Groundwater samples were collected from the boreholes drilled during the soils investigation, and monitoring wells surrounding the landfill were sampled. At least two groundwater zones, the USZ and the LSZ, were found to exist underneath Landfill 3: the USZ and the LSZ. Four monitoring wells were screened in the USZ and two in the LSZ.

The water samples collected from the soil borings are representative of the quality of the USZ groundwater in this area of the landfill. The following conclusions can be drawn concerning the groundwater results from these samples:

- As expected, the highest concentrations of organic compounds were detected in the groundwater sample from the sludge dump borehole. Eight VOCs and 11 SVOCs were detected in this sample. Concentrations were typically greater than 1,000 μg/L with trans-1,2-dichloroethene registering the highest concentration at 240,000 μg/L. Nine organics and six metals were detected at elevated concentrations.

- Groundwater samples from boreholes in the former trench area showed evidence of organic and inorganic contamination. Three VOCs, one SVOC, two PCBs, and seven metals were detected above MCLs.

- Only one organic compound, trans-1,2-dichloroethene, was detected in groundwater above MCLs at the lead contaminated area. Barium and lead were also detected above the MCLs.

Monitoring wells 2A, 3A, 4A, and 76A were sampled to determine the quality of USZ groundwater. These wells were sampled during the RI groundwater investigation and continue to be sampled as part of the ongoing groundwater monitoring program at Tinker AFB. Benzene, methylene chloride, trichloroethene, vinyl chloride, and bis(2-ethylhexyl)-phthalate were detected at elevated concentrations, some exceeding MCLs. Barium, cadmium, lead, manganese, and nickel were detected at concentrations exceeding MCLs. The concentrations of contaminants in these USZ monitoring wells were, in general, significantly below the concentrations detected in groundwater samples from the boreholes within the landfill.

Monitoring wells 4B and 76B were sampled to determine the quality of LSZ groundwater. These wells were sampled during the RI groundwater investigation and continue to be sampled as part of the ongoing groundwater monitoring program at Tinker AFB. Methylene chloride and bis(2-ethylhexyl)phthalate were detected at concentrations exceeding MCLs. Lead and manganese were detected at concentrations exceeding MCLs. The concentrations of contaminants in these LSZ monitoring wells were, in general, typically below those in USZ monitoring wells.

An exposure assessment was performed to determine the potential human receptors and analyzed the potential exposure pathways at Landfills 1 through 4. The following conclusions have been drawn concerning potential receptors:

- Potentially exposed human populations were limited to industrial workers associated with Base operations.
- No sensitive subpopulations were identified within the industrial site workers determined to represent the potentially exposed population at the sites.
- The only complete exposure pathways identified during the exposure assessment are inhalation of contaminated soil particles and inhalation of organic vapors from contaminated soil.
- In general, wildlife on the Base is typically tolerant of human activities and urban environments.
- No federal threatened or endangered species have been reported at the Base.

9.0 Recommendations

This chapter describes additional work recommended for the Phase II RFI. Additional investigations are required to fully characterize the nature and extent of contamination, and the risks to human health and the environmental at Landfill 3. Based on the location of this site, it will be more appropriate to investigate it as part of a group comprising several waste units in close proximity: RWDS 1030W, RWDS 1022E, RWDS 62598, Landfills 1, 2, and 4, the SP, and FTA1. Details of specific sampling needs will be presented in the work plan/sampling plan for the Phase II RFI.

Review of Landfills 1 through 4 RI Report. Upon comparison of the RI report (USACE, 1993) summary tables of analytical results presented in Volume I and of the available laboratory results presented in Volumes 3 and 4, numerous discrepancies were noted. A thorough review should be performed to resolve the discrepancies. The accuracy of these summary tables is crucial to the text of the RI. In addition, not all of the laboratory results were present to completely verify results listed in the summary tables.

In the previous investigations, data has been collected to characterize contaminated soils and groundwater within the landfill and investigate groundwater contamination around the perimeter of the landfill. A Phase II field investigation is recommended to perform the following tasks:

- Install additional monitoring wells in the HWBZ, USZ, and LSZ to characterize and determine the lateral and vertical extent of groundwater contamination originating from Landfill 3.
- Perform additional soil sampling in areas were elevated levels of contamination were detected to determine the extent of contamination.
- Perform aquifer testing to obtain data to evaluate potential transport and migration of contaminants.
- Perform a baseline risk assessment to assess potential impacts to human health and the environment.

Install Additional Groundwater Monitoring Wells. The current well control adjacent to Landfill 3 is limited to four wells completed in the USZ (MW-2A, 3A, 4A, 76A) and two wells completed in the LSZ (MW-4B and 76B). Additional monitoring wells are needed to:

- Delineate and monitor the HWBZ and USZ separately as opposed to the USZ as currently defined in this report, which includes both zones.

- Determine the direction of localized groundwater flow within the HWBZ, USZ, and LSZ.

- Determine the vertical extent of contamination in the LSZ.

Installation of three 3-well clusters and one deep well around the landfill is recommended. Each well cluster will include wells completed in the HWBZ, USZ, and LSZ. One well cluster will be positioned on the northeast side of the landfill southwest of Crutcho Creek between MW-3 and MW-4. The second well cluster will be centered due south of the landfill. The third well cluster will be centered due west of the landfill. A deep well completed in the LSZ is recommended northeast of the landfill adjacent to MW-2. Every monitoring well will have a 10-foot screen unless geologic conditions require shorter screens. All monitoring wells will be added during the Phase II RFI as part of the basewide groundwater investigation. The proposed well configuration along with the existing wells will provide adequate well control to determine groundwater flow direction and background versus downgradient contaminant concentrations within all three zones.

All existing and newly installed wells should be sampled and submitted for laboratory analysis of VOCs, SVOCs, metals, inorganic parameters, and radionuclides.

Aquifer slug testing should be performed in selected wells to obtain data to calculate groundwater flow rates. Slug tests should be performed at least in one upgradient and one downgradient well for each zone.

Due to the close proximity of Landfills 1 through 4 and other adjacent waste units, attempting to track the migration of specific contaminants at a distance from the perimeter of a single landfill may not be practical. In determining the lateral extent of contaminated groundwater associated with the landfills, it is recommended that the four landfills and the adjacent waste units be considered as a single point source. Using this assumption, monitoring wells will be installed around the perimeter of these waste units to establish the lateral extent of contaminants in groundwater.

After the completion of the Phase II field investigation, a baseline risk assessment should be performed to evaluate potential threats to human health and the environment.

In addition, to fully evaluate the extent of soil contamination at this site it is recommended that site-specific soil background samples be collected during the Phase II RFI. This additional information along with the USGS background values should be used in the Phase II report to distinguish site-related from background concentrations in a statistically significant manner. During the development of the Phase II RFI work plan, the number of background samples to be collected, the location of the soil borings, and the soil analysis to be performed on the samples should be determined for EPA approval.

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Final Report
Phase I RCRA Facility Investigation for Appendix I Sites

VOLUME VII

SWMU-6, Landfill No. 4

Department of the Air Force
Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma

September 1994

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List of Acronyms

AFB	Air Force Base
ARA	Applied Research Associates, Inc.
AOC	area of concern
B&V	B&V Waste Science and Technology Corporation
BTEX	benzene, toluene, ethyl benzene, and xylene
CAL	corrective action levels
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/s	centimeters per second
CMS	Corrective Measures Study
COD	chemical oxygen demand
DERP	Defense Environmental Restoration Program
DOD	U.S. Department of Defense
EID	Engineering Installation Division
EPA	U.S. Environmental Protection Agency
ES	Engineering Science
ft/ft	foot per foot
HARM	hazardous assessment rating methodology
HSWA	Hazardous and Solid Waste Amendments
HWBZ	Hennessey water bearing zone
IRP	Installation Restoration Program
LIF-CPT	Lazar-Induced Fluorescence-Electronic Cone Penetrometer Test
LSZ	lower saturated zone
μg/kg	micrograms per kilogram
μg/L	micrograms per liter
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
msl	mean sea level
NAAQS	National Ambient Air Quality Standards
NCP	National Oil and Hazardous Substance Pollution Contingency Plan
NPL	National Priorities List
PAH	polyaromatic hydrocarbons
PA/SI	preliminary assessment/site investigation

PCA	tetrachloroethane
PCB	polychlorinated biphenyl
pCi/L	picocuries per liter
PRC	PRC Environmental Management, Inc.
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RI/FS	remedial investigation
RFI	RCRA Facility Investigation
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SGI	soil gas investigation
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TOC	total organic carbon
TOX	total organic halogens
TPH	total petroleum hydrocarbons
TSD	treatment, storage, and disposal (facility)
USACE	U.S. Army Corps of Engineers
USC	U.S. Code
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USZ	upper saturated zone
UWBZ	upper water bearing zone
VOC	volatile organic compounds
yd^3	cubic yards

Executive Summary

This report provides a summary of the various investigations that have been conducted at the solid waste management unit (SWMU)-6, Landfill No. 4 (Landfill 4), Tinker Air Force Base (AFB), Oklahoma. The report has been prepared to determine and document whether sufficient investigations at Landfill 4 have been performed to meet regulatory requirements. Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County. The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south. The Base encompasses approximately 5,000 acres.

Background. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon^{TM}, jet fuels, and radium paints.

In 1984, Congress amended the Resource Conservation and Recovery Act (RCRA) with the Hazardous and Solid Waste Amendments (HSWA), which allow U.S. Environmental protection Agency (EPA) to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or contaminants from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989, Tinker AFB submitted its Part B permit application for renewal of its operating RCRA Hazardous Waste Storage facility permit. The final RCRA HSWA permit issued on July 1, 1991, requires Tinker AFB to investigate all SWMUs and areas of concern (AOC) and to perform corrective action at those identified as posing a threat to human health or the environment. The permit specifies that a RCRA Facility Investigation (RFI) be conducted for 43 identified SWMUs and two AOCs on the Base. This document has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 4.

Source Description. Landfill 4 was active during the period from 1962 to 1968. The landfill was used primarily for the disposal of general refuse, but drums of materials including solidified solvents and metal shavings were also deposited in the landfill area. Landfill 4 was constructed by excavating a series of trenches oriented east to west, with several inches of excavated native soil being placed daily on the landfill trenches, and a final cover of 3 to 4 feet of soil being placed on the trenches upon closure of the site. One specific-use sludge dump was located in the central portion of the landfill. This area was used for landfarming sludges taken from the bottom of petroleum and solvent storage tanks. Approximately 320,000 cubic yards (yd^3) of waste materials are estimated to have been deposited in Landfill 4.

Site Investigations. The initial phase of the investigations conducted at Tinker AFB was conducted by Engineering Science (ES, 1982). The purpose of this study was to conduct a literature search for the various potentially contaminated sites in order to determine from records what was actually disposed of at these sites. ES concluded that Landfill 4 had a high potential for contaminant migration.

The second phase involved investigations to confirm the presence of contamination and determine the nature and the extent of contamination at the different sites. In 1983-84, Radian Corporation (Radian) was retained to perform these investigations. Field activities conducted during the Radian study involved the drilling of two new monitoring wells, one to the west and one to the south of Landfill 4. A surface leachate sample was collected from the west bank of the landfill. The report concluded that the analytical data showed only a limited impact of the landfill on groundwater quality. Total organic halogens (TOX) were detected in both monitoring wells. The leachate sample was typical of sanitary landfill leachate, high in total organic carbon (TOC) and iron, but with a TOX value of 1,500 micrograms per liter (μg/L), suggesting the presence of chlorinated organic compounds.

The U.S. Army Corps of Engineers (USACE) conducted a remedial investigation (RI) at SWMUs 3 through 6, Landfills 1 through 4 from 1986 to 1990. In 1987, 6 soil borings were advanced into the former trench areas and sludge dump. One sample was collected from each boring. In addition, surface soils were sampled at two locations within the landfill. Elevated levels of volatile organic compounds (VOC), semivolatile organic compounds (SVOC), and metals were detected in the subsurface samples, with the highest contaminant concentrations detected in borings in the sludge dump and west of the sludge dump. Surface soil samples were significantly less contaminated than subsurface samples.

Ten additional soil samples were collected in the vicinity of the sludge dump during a 1992 study performed by Applied Research Associates, Inc (ARA). Elevated concentrations of VOCs, polyaromatic hydrocarbons (PAH), and metals were detected.

A shallow soil gas investigation (SGI) was conducted at Landfill 4 in 1990. Soil gas samples were analyzed for methane, fuel components (benzene, toluene, ethyl benzene, and xylene [BTEX]), three chlorinated VOCs, and total petroleum hydrocarbons (TPH). Elevated concentrations of methane were detected across most of the landfill. Smaller soil gas plumes of fuel components and chlorinated hydrocarbons were also detected.

Surface leachate samples were collected in 1979, 1984, and 1987. The results of the 1979 sampling indicated high concentrations of chemical oxygen demand (COD), oil and grease, phenols, and heavy metals. The 1984 and 1987 results found lower concentrations of contaminants, although VOCs, SVOCs, and metals were detected in the samples.

During the RI, trench water samples were collected from soil borings advanced into the landfill. Elevated concentrations of VOCs, SVOCs, metals, and radiometric parameters were detected. The highest concentrations of contaminants were found in groundwater taken from borings at the sludge dump and west of the sludge dump.

The USACE sampled groundwater from monitoring wells in the vicinity of the landfill during RI activities from 1986 to 1990. Since 1990, selected monitoring wells have been sampled as part of an on-going groundwater monitoring program. VOCs, SVOCs, metals, and radiometric parameters were detected in some samples, but at concentrations significantly below those in trench water samples from landfill borings.

An exposure assessment was performed to determine the potential human receptors and analyzed the potential exposure pathways at Landfills 1 through 4. Potentially exposed human populations were limited to industrial workers associated with Base operations. The only complete exposure pathways identified during the exposure assessment are inhalation of contaminated soil particles and inhalation of organic vapors from contaminated soil. In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base.

Conclusions. The results of the soils investigations at Landfill 4 revealed the following:

- Elevated levels of VOCs, SVOCs, and metals were detected in subsurface samples from landfill borings. The highest concentrations of organic contaminants were detected at borings L4-2 and L4-3 in the vicinity of the sludge dump, and at boring L4-5 west of the sludge dump. Several metals were consistently detected at elevated levels.

- Some organic contamination was also detected in surface soil samples, but concentrations were significantly below those detected in subsurface samples. Elevated levels of some metals were also detected in surface soil samples.

The results of the SGI revealed the following:

- Concentrations of all the analytes were detected in soil gas with the exception of xylene. A significant methane plume was detected across most of the landfill with the highest concentrations in the general area of soil boring L4-5.

- Of the fuel components, the benzene plume was the largest and registered the highest concentrations. Smaller plumes of ethyl benzene and toluene were detected.

- One significant trichloroethane plume was detected, centered in the sludge dump and stretching to the north and the west. Smaller plumes of trichloroethene and tetrachloroethene were detected.

- A significant TPH plume was found with maximum concentrations located in the sludge dump and the boring L4-5 area.

The following conclusions can be drawn from the results of surface water sampling and analysis:

- There were locations along the northern and western slopes of the landfill where groundwater was at or near ground surface. These were the locations of leachate surface flows during and after periods of precipitation.

- VOCs, SVOCs, metals, and elevated concentrations of indicator parameters such as COD, oil and grease, and phenols were detected in leachate samples. The concentrations of contaminants in more recent samples have not been as high as the initial samples collected in 1979.

The following conclusions can be drawn from the results of the groundwater investigations at the landfill:

- The groundwater beneath Landfill 4 exists in three distinct zones: the Hennessey water bearing zone (HWBZ), the upper saturated zone (USZ), and lower saturated zone (LSZ). Due to the complex stratigraphy and limited well control, the HWBZ and the USZ are considered as a single zone for the purposes of this report. The lower saturated zone is considered to be the top of the regional zone.

- The HWBZ is hydraulically connected to the former trenches, sludge dump, and USZ, within the landfill. Analyses performed on HWBZ trench water samples collected from soil borings within the landfill detected elevated concentrations of VOCs, SVOCs, metals, and radiometric parameters.

- Although VOCs, SVOCs, metals, and radiometric parameters were also detected in some groundwater samples from monitoring wells adjacent to Landfill 4, the many contaminants were detected sporadically, and the concentration of most contaminants were significantly below those detected in trench water from landfill borings, indicating that only limited contamination is migrating to groundwater zones outside the landfill.

Recommendations. The following are recommendations for additional work to be done during the Phase II RFI:

- Review summary tables of analytical results in the RI report for accuracy.

- Collect site-specific soil background samples to be used in addition to USGS soil data to distinguish site-related from background concentrations in a statistically significant manner during the Phase II investigation.

- Evaluate the results of the 1990 SGI to determine if hot spots exist outside the sludge dump area that would warrant further investigation. In particular, the area around boring L4-5 appears to warrant additional work.

- Determine the adequacy of current background well locations.

- Determine background groundwater concentrations for radiological parameters for comparison with analytical results from monitoring well samples.

- A Phase II field investigation is recommended to perform the following tasks:

  - Collect additional soil samples from borings L4-2 and L4-3 for polychlorinated biphenyl (PCB) analysis. The elevated detection limits in previous analyses may have missed PCBs if present.

  - Further investigate soils in the area of sludge dump boring L4-2 to determine the source of radioactive contamination, and its lateral and vertical extent.

  - Verify the existence of monitoring wells associated with Landfill 4 presented in the RI report.

  - Install additional groundwater monitoring wells to characterize the lateral and vertical extent of groundwater contamination originating specifically from Landfill 1.

- Perform aquifer slug tests on selected wells to obtain data to determine groundwater flow rates and evaluate potential migration of contaminants.

- Perform a baseline risk assessment to assess potential impacts to human health and the environment.

1.0 Introduction

1.1 Purpose and Scope

This document has been prepared in response to the U.S. Department of the Air Force, Tinker Air Force Base (AFB), Oklahoma request for a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) Summary Report for solid waste management unit (SWMU)-6, Landfill No. 4 (Landfill 4).

The objective of this RFI Summary Report is to provide Tinker AFB with one comprehensive report that summarizes the various investigations that have occurred at Landfill 4 since the first environmental investigation was initiated on Base in 1981. The purpose of this comprehensive summary document is to:

- Characterize the site (Environmental Setting).
- Define the source (Source Characterization).
- Define the degree and extent of contamination (Contamination Characterization).
- Identify actual or potential receptors.
- Identify all action levels for the protection of human health and the environment.

Additionally, this document briefly describes the procedures, methods, and results of all previous investigations and baseline risk assessments that relate to Landfill 4 and contaminant releases, including information on the type and extent of contamination at the site, and actual or potential receptors. Where previous investigations, reports, or studies were not comprehensive and did not furnish the information required to determine the nature and extent of contamination, future work that can be conducted to complete the investigation has been recommended.

1.2 Preface

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to address the cleanup of hazardous waste disposal sites across the country. CERCLA gave the president authority to require responsible parties to remediate the sites or to undertake response actions through use of a fund (the Superfund). The president, through Executive Order 12580, delegated the U.S. Environmental Protection Agency (EPA) with the responsibility to investigate and remediate private party hazardous waste disposal sites that created a threat to human health and the environment. The president delegated responsibility for investigation and cleanup of federal facility disposal sites to the various federal agency heads. The Defense Environmental Restoration Program (DERP) was formally

established by Congress in Title 10 U.S. Code (USC) 2701-2707 and 2810. DERP provides centralized management for the cleanup of U.S. Department of Defense (DOD) hazardous waste sites consistent with the provisions of CERCLA, as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations [CFR] 300), and Executive Order 12580. To support the goals of DERP, the Installation Restoration Program (IRP) was developed to identify, investigate, and clean up contamination at installations.

Under the Air Force IRP, Tinker AFB began a Phase I study similar to a preliminary assessment/site investigation (PA/SI) in 1981 (Engineering Science [ES], 1982). This study helped locate 14 sites that needed further investigation. Phase II studies were performed in 1983 (Radian Corporation [Radian], 1985 a,b).

In 1986, Congress amended CERCLA through SARA. SARA waived sovereign immunity for federal facilities. This act gave EPA authority to oversee the cleanup of federal facilities and to have the final authority for selecting the remedial action at federal facilities placed on the National Priorities List (NPL) if the EPA and the relevant federal agency cannot concur in the selection. Congress also codified DERP (SARA Section 211), establishing a fund for the DOD to remediate its sites because the Superfund is not available for the cleanup of federal facilities. DERP specifies the type of cleanup responses that the fund can be used to address.

In response to SARA, the DOD realigned its IRP to follow the investigation and cleanup stages of the EPA:

- PA/SI
- Remedial investigation/feasibility study (RI/FS)
- Record of Decision (ROD) for selection of a remedial action
- Remedial design/remedial action.

In 1984, Congress amended RCRA with the Hazardous and Solid Waste Amendments (HSWA) which allow the EPA to require, as a permit condition, a facility to undertake corrective action for any release of hazardous waste or constituents from any SWMU at a treatment, storage, and disposal (TSD) facility. On January 12, 1989 Tinker AFB submitted its Part B permit application for renewal of its operating RCRA hazardous waste storage facility permit.

EPA, in the Hazardous Waste Management Permit for Tinker AFB, dated July 1, 1991, identified 43 SWMUs and two areas of concern (AOC) on Tinker AFB that need to be addressed. This permit requires Tinker AFB to investigate all SWMUs and AOCs and to perform corrective action at those identified as posing a threat to human health or the environment. This RFI Summary Report has been prepared to determine whether sufficient investigations have been conducted to meet the permit requirements for Landfill 4 and to document all determinations.

1.3 Facility Description

Tinker AFB is located in central Oklahoma, in the southeast portion of the Oklahoma City metropolitan area, in Oklahoma County (Figure 1-1) with its approximate geographic center located at 35° 25' latitude and 97° 24' longitude (U.S. Geological Survey [USGS], 1978). The Base is bounded by Sooner Road to the west, Douglas Boulevard to the east, Interstate 40 to the north, and Southeast 74th Street to the south (Figure 1-2). An additional area east of the main Base is used by the Engineering Installation Division (EID) and is known as Area D. The Base encompasses approximately 5,000 acres. Tinker AFB began operations in 1942 and serves as a worldwide repair depot for a variety of aircraft, weapons, and engines. These activities require the use of hazardous materials and result in the generation of hazardous wastes. These wastes have included spent organic solvents, waste oils, waste paint strippers and sludges, electroplating wastewaters and sludges, alkaline cleaners, acids, Freon™, jet fuels, and radium paints. Wastes that are currently generated are managed at two permitted hazardous waste storage facilities. However, prior to enactment of RCRA, industrial wastes were discharged into unlined landfills and waste pits, streams, sewers, and ponds. Past releases from these landfills, pits, etc., as well as from underground tanks, have occurred. As a result, there are numerous sites of soil, groundwater, and surface water contamination on the Base.

The various reports generated as a result of investigative activities conducted at the Landfill 4 have been reviewed and evaluated in terms of the sites' status under RCRA regulations. A summary based on the review of these reports for Landfill 4 is presented in the following chapters and sections. In addition, recommendations for additional work is given at the end of the summary report.

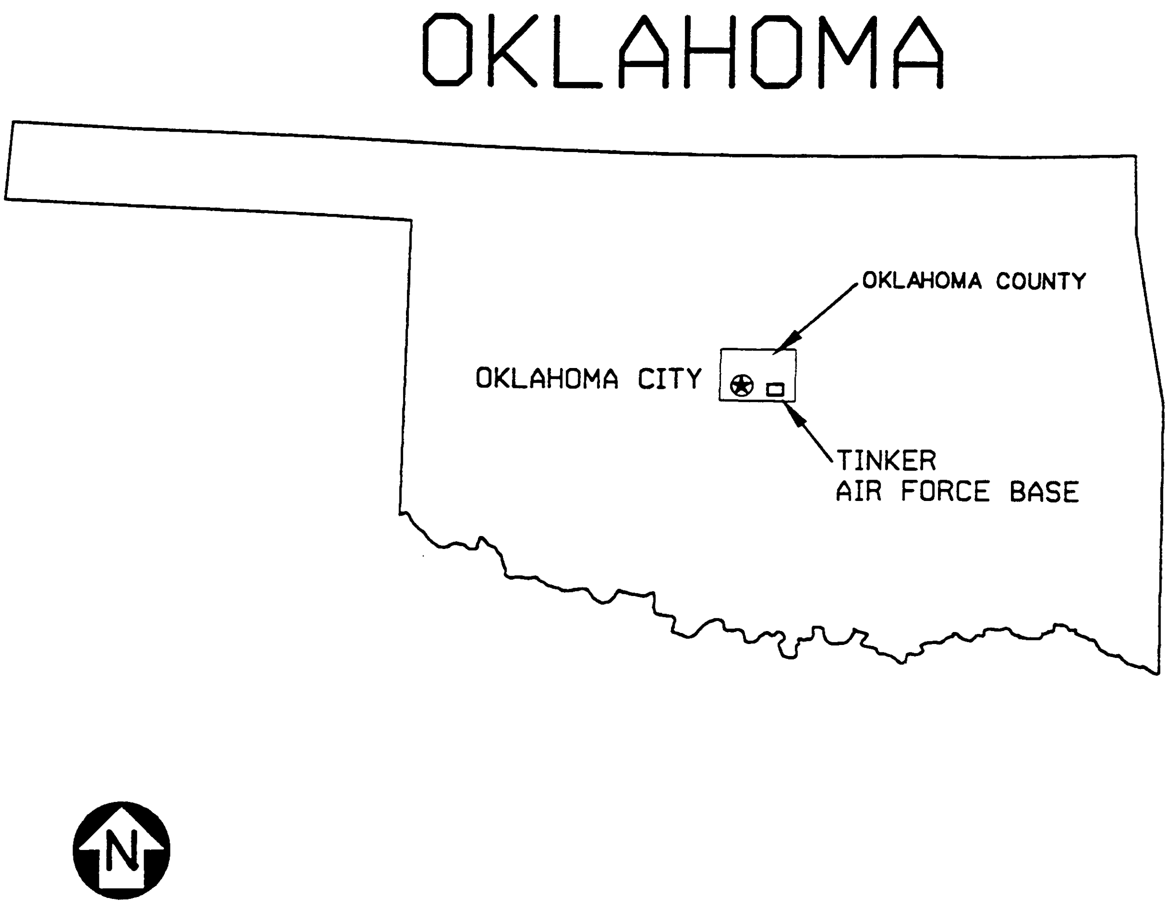

FIGURE 1-1
TINKER AIR FORCE BASE
OKLAHOMA
STATE INDEX MAP

PREPARED FOR
TINKER AFB
OKLAHOMA

STARTING DATE: 03/17/94 | DATE LAST REV.: | DRAFT. CHCK. BY:G. PACHECO | INITIATOR: C. WALLACE | DWG. NO.:
DRAWN BY:P.O. TERRY | DRAWN BY: | ENGR. CHCK. BY: C. WALLACE | PROJ. MGR.:J. TAYLOR | PROJ. NO.:

3/23/94 POT
FILENAME: G:\TINKER\40983202.075

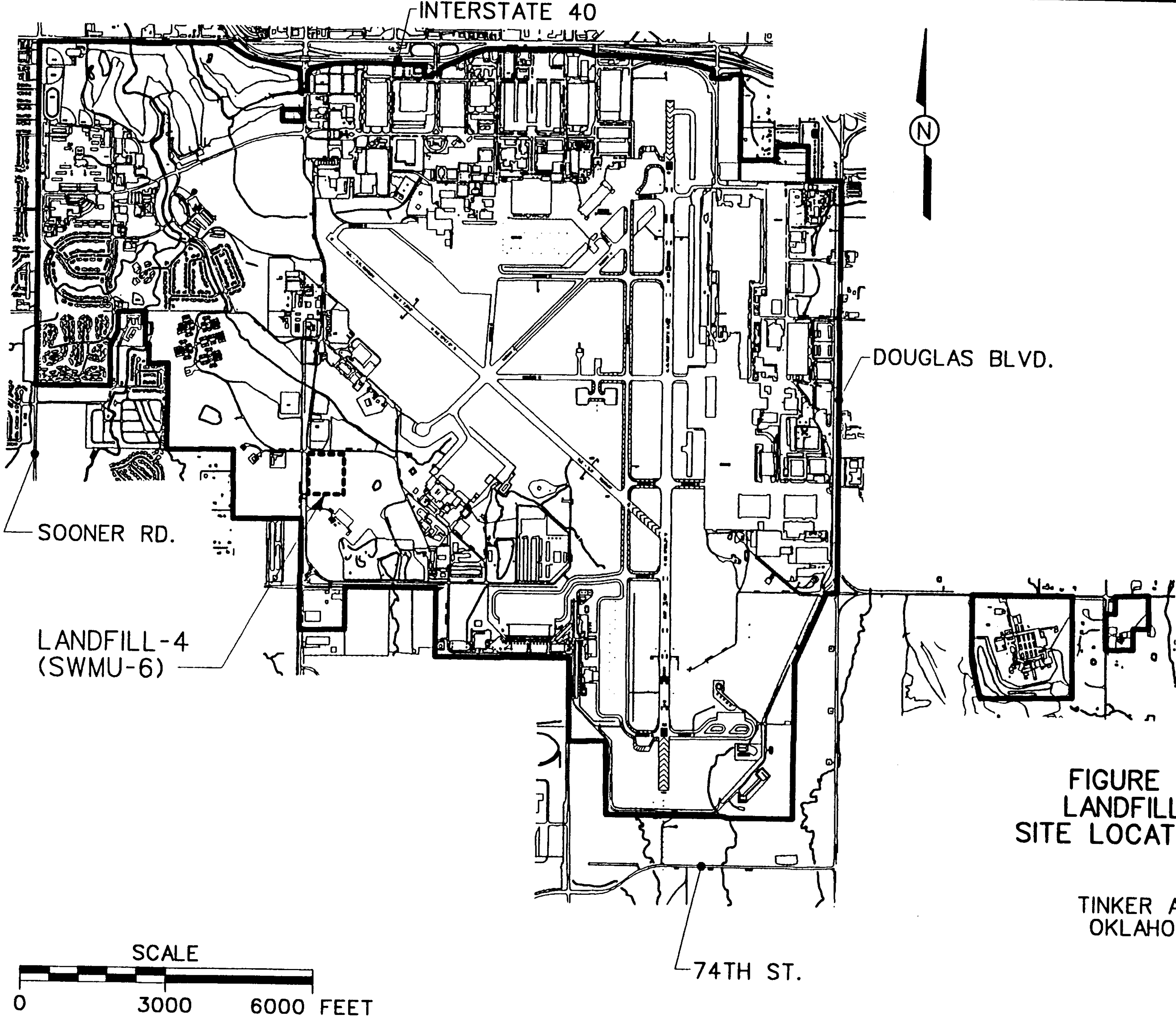

FIGURE 1-2
LANDFILL 4
SITE LOCATION MAP

TINKER AFB
OKLAHOMA

STARTING DATE: 3/18/94	DATE LAST REV.:	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P.O. TERRY	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

FILENAME: G:\TINKER\40983202.094

1.4 Site Description

Landfill 4 occupies approximately 12.4 acres and is located in the southwest corner of Tinker AFB. The site is south of Landfill Road and east of Patrol Road. The sample locations of Landfill 4 are shown in Figure 1-3.

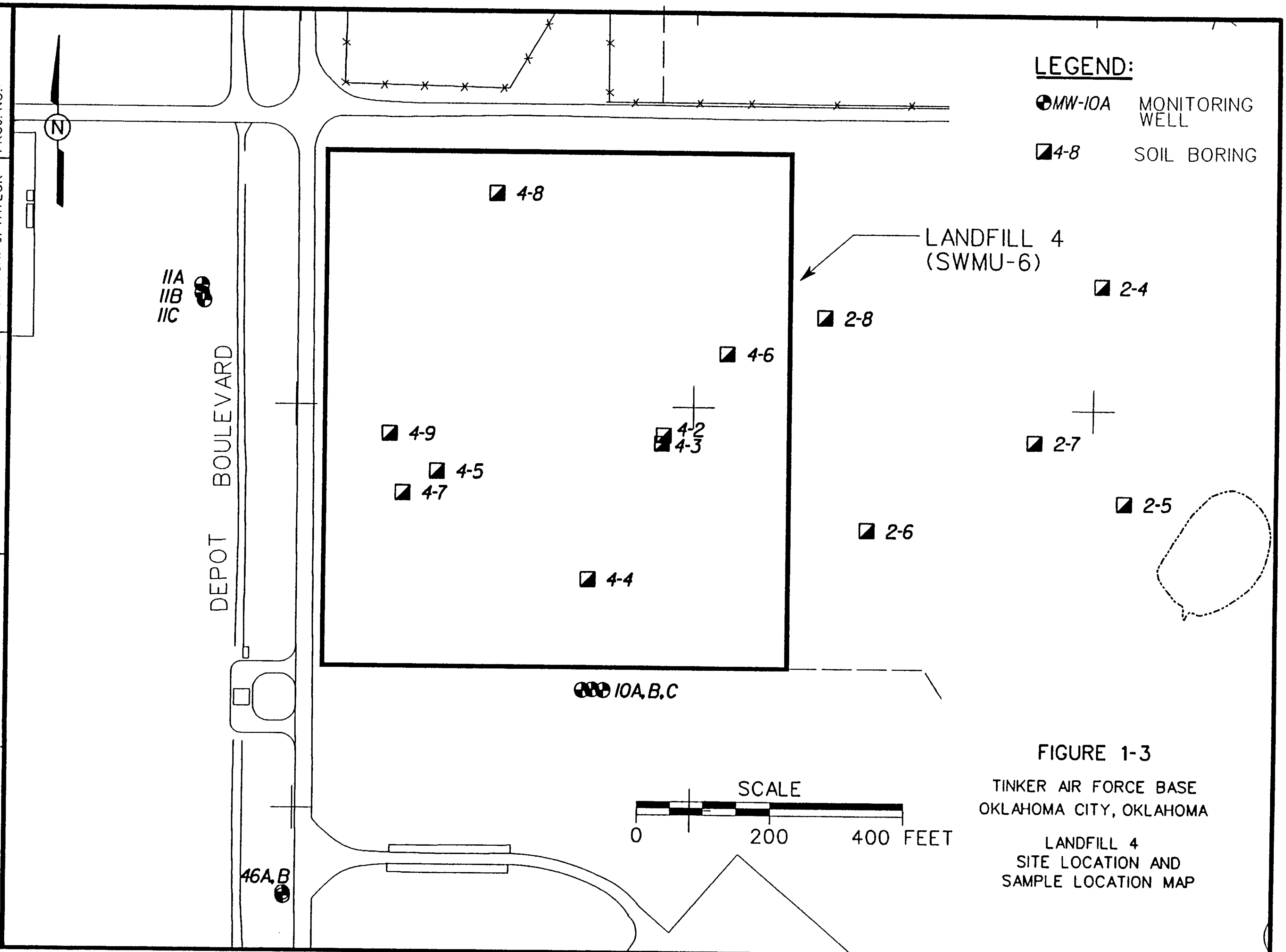

FIGURE 1-3

TINKER AIR FORCE BASE
OKLAHOMA CITY, OKLAHOMA

LANDFILL 4
SITE LOCATION AND
SAMPLE LOCATION MAP

STARTING DATE: 01/14/94 -	DATE LAST REV.: / /	DRAFT. CHCK. BY: G. PACHECO	INITIATOR: C. WALLACE	DWG. NO.:
DRAWN BY: P. TERRY	DRAWN BY:	ENGR. CHCK. BY: C. WALLACE	PROJ. MGR.: J. TAYLOR	PROJ. NO.:

FILENAME:G:\TINKER\40983202.007

2.0 Background

2.1 Site Operations and History

Tinker AFB was originally known as the Midwest Air Depot and began operations in July 1941. The site was activated March 1942. During World War II, the depot was responsible for reconditioning, modifying, and modernizing aircraft, vehicles, and equipment.

General refuse generated from these operations has been disposed of in at least six landfills located on the Base property or on leased land adjacent to the Base. Landfill 4 was active during the period from 1962 to 1968. The landfill was used primarily for the disposal of general refuse, but drums of materials including solidified solvents and metal shavings were also deposited in the landfill. Landfill 4 was constructed by excavating a series of trenches oriented east to west, with several inches of excavated native soil being placed daily in the landfill trenches, and a final cover of 3 to 4 feet of soil being placed over the trenches upon closure of the site. One specific-use sludge dump was located in the central portion of the landfill. This area was used for landfarming sludges taken from the bottom of petroleum and solvent storage tanks. Approximately 320,000 cubic yards (yd^3) of waste materials are estimated to have been deposited in Landfill 4.

2.2 Summary of Previous Investigations

Engineering Science, Inc. Landfill 4 was among 14 sites identified during the IRP Phase I assessment completed by ES in April 1982. The purpose of the study was to identify the potential for contamination from past waste disposal practices and to assess the potential for contaminant migration. ES's work scope included activities such as reviewing site records, interviewing personnel, defining the environmental setting, and determining quantities and locations of current and past hazardous waste storage, treatment, and disposal. ES assigned a hazardous assessment rating methodology (HARM) score of 70 to the site, and ranked the site as a priority 1 of 14. ES concluded that Landfill 4 had a high potential for contaminant migration.

Radian Corporation. IRP Phase II field investigations were initiated in 1983 by Radian. The purpose of these efforts was to determine if any environmental contamination had occurred due to disposal and management practices at the sites identified in the Phase I report by ES. Radian's Phase II, Stage 1 field activities conducted during February 1984 involved the drilling of two new monitoring wells, one to the west and one to the south of Landfill 4. A surface leachate sample was collected from the west bank of the landfill. The report concluded that the analytical data showed only a limited impact of the landfill on groundwater quality. Total organic halogens (TOX) were detected in both monitoring wells at 60 micrograms per liter (µg/L). The leachate sample was typical of sanitary landfill leachate, high in total organic carbon (TOC) and iron, but with a TOX value of 1500 µg/L, suggesting the presence of chlorinated organic compounds.

Radian's Phase II, Stage 2 field activities conducted from June through October 1984 did not involve any additional groundwater testing or soil borings at Landfill 4.

U.S. Army Corps of Engineers. Tinker AFB employed the U.S. Army Corps of Engineers (USACE) from 1986 to 1990 to conduct an RI of Landfills 1 through 4 (SWMUs 3 through 6) (USACE, 1993). The USACE assessed the magnitude and extent of contamination originating from past disposal practices at the landfill. The RI scope of work included records searches, subsurface geologic explorations, installation and sampling of monitoring wells, sampling of water and solid waste from landfill trenches, and explorations to determine the extent of the waste boundary.

During RI activities performed by the USACE at Landfill 4, two surface and six subsurface soil samples were collected and analyzed for volatile organic compounds (VOC), semivolatile organic compounds (SVOC), metals, pesticides, polychlorinated biphenyls (PCB), and indicator parameters such as TOC, cyanide, pH, conductivity, and phenols. VOCs, SVOCs, and metals were detected in landfill soils.

Groundwater quality in the vicinity of Landfill 4 was investigated by sampling trench water from soil borings within the landfill and from selected groundwater monitoring wells adjacent to the landfill. Hydrogeological studies determined that three groundwater aquifers exist under Landfill 4: the Hennessey water bearing zone (HWBZ), the upper saturated zone (USZ), and the lower saturated zone (LSZ). Due to the complex stratigraphy and limited well control the HWBZ and the USZ will be considered one zone for the purposes of this report. Nine trench water samples were collected from soil borings within the landfill to characterize the groundwater contamination within the USZ caused by historical waste disposal practices. The trench water samples were found to be contaminated with VOCs, SVOCs, metals, and radiometric parameters.

Monitoring wells installed in and around the landfill in the USZ and LSZ were sampled to determine the magnitude and extent of contaminant migration. Monitoring wells 10A, 10B, 11C, and 46B are adjacent to the landfill in the USZ. Monitoring well 10C is screened in the LSZ of the landfill. Groundwater in the vicinity of the landfill was found to be contaminated with VOCs, SVOCs, metals, and radiometric parameters, but the concentrations detected were significantly lower than those found in trench water from landfill borings. Monitoring well 46A is screened in both the USZ and LSZ and, therefore, will not be considered in this report.

In February 1991, the USACE issued a preliminary draft baseline risk assessment for Landfills 1 through 4. Seven organic chemicals and two inorganic chemicals were determined to be chemicals of potential concern at these sites. Inhalation of contaminated particles and inhalation of organic vapors were the only completed exposure pathways identified in the risk assessment. Industrial site workers were the only potentially exposed population. All carcinogenic and noncarcinogenic risks associated with the site were within acceptable risk levels for CERCLA sites.

PRC Environmental Management, Inc. PRC performed a RCRA Facility Assessment (RFA) in 1989 to identify and assess the potential for release of hazardous waste or hazardous constituents from SWMUs and other AOCs, as well as to evaluate the need for further investigations under the authority of Section 3004 (u) of RCRA, as amended by the HSWA of 1984. The RFA report incorporated the results of a review of the file materials available from EPA Region VI and a visual site inspection performed May 15 to 19, 1989. The assessment of Landfill 4 concluded that there was a high potential for release of hazardous waste or hazardous constituents to soil, groundwater, and surface water; a moderate potential existed for release of hazardous constituents to air; and high potential existed for the generation of subsurface gas.

B&V Waste Science and Technology Corporation. Tinker AFB employed B&V in 1989 to evaluate alternative cover systems for Landfill 4 and investigate the need to relocate utility systems within the vicinity of the landfill. B&V recommended a natural soil cover with synthetic water barrier and gas control layers.

During the 1990 LIF-CPT study, ARA collected five groundwater samples from the USZ for VOC analysis. Two of the samples were analyzed on site, and the remaining three samples were submitted for off-site analysis. Table 5-7 presents a summary of the analytical results for these samples.

Monitoring wells installed in the vicinity of the landfill in the USZ and the LSZ were sampled to determine the magnitude and extent of contaminant migration. Groundwater samples were collected from nearby wells by the USACE from 1986 to 1990 during the RI, and selected monitoring wells have been sampled as a part of the Base groundwater monitoring program. Monitoring wells 10A, 10B, 11C, and 46B in the vicinity of Landfill 4 are screened in the USZ, while monitoring well 10C is screened in the LSZ. Well 46A is located in the vicinity of Landfill 4; however, it is screened across both the USZ and the LSZ and, therefore, will not be used to characterize either zone. A summary of the 1986 to 1992 groundwater results are presented in Table 5-8 for the USZ and in Table 5-9 for the LSZ.

5.1 Constituents of Potential Concern

The results of soil, soil gas, surface water, and groundwater analyses of samples collected from Landfill 4 are available from past IRP investigation activities. Evaluation of these analytical results for the purpose of identifying constituents of potential concern with respect to both human health and the ecological impacts has not been performed. However, an interpretation has been made comparing the analytical results to USGS background concentrations in soils and groundwater. The following sections summarize these interpretations.

5.2 Soil Characterization

During the RI, the USACE assessed the magnitude and extent of contamination originating from historical landfill disposal practices. In 1987, six soil borings (L4-1 through L4-6) were advanced into the former trench areas within the landfill. One sample was collected from each boring. In addition, surface soils were sampled at two locations within the landfill. The soil samples were analyzed for VOCs, SVOCs, metals, and indicator parameters. The results of the 1987 surface and subsurface soil investigations are presented in Table 5-2.

Fourteen VOCs and nine SVOCs were detected in the trench boring samples. The highest concentrations of organic contaminants were found in boring L4-5. The highest organic concentration detected was for 2-butanone at 200,000 microgram per kilogram (μg/kg). Other organic compounds with elevated concentrations included acetone (23,000 μg/kg), 2-hexanone (5,600 μg/kg), 4-methyl-2-pentanone (5,530 μg/kg), phenol (5,500 μg/kg), diethyl phthalate

In 1992, B&V issued a pre-final design analysis and construction specifications for the selected cover at Landfill 4. The cover system consisted of the following layers in order of construction placement:

- Fill layer to achieve the basic 3 to 5 percent initial slope and drainage patterns
- Gas collection layer consisting of a synthetic drainage composite, or two layers of filter fabric sandwiched around a synthetic drainage net
- A 6-inch layer of compacted clay meeting the permeability specification of 1 x 10^{-7} centimeters per second (cm/s) or less
- A geosynthetic composite liner consisting of either a sandwich of filter fabric around a bentonite layer, or a bentonite layer attached to a flexible membrane liner
- A 40-mil flexible membrane liner
- A synthetic drainage net
- Filter fabric
- A 24-inch layer of fill material used to protect the other cover components
- Six inches of topsoil with vegetation.

Tracer Research Corporation. The USACE employed Tracer to conduct a shallow soil gas investigation (SGI) at Landfills 2 and 4 in July 1989 and March 1990. The purpose of the SGI was to define the nature and extent of volatiles present in the subsurface, and to assist in determining the placement of borings for additional soil and groundwater investigations. A total of 114 soil/gas samples were collected for the two landfills.

Applied Research Associates, Inc (ARA). The U.S. Air Force employed ARA in 1992 to demonstrate the effectiveness of a prototype Laser-Induced Fluorescence-Electronic Cone Penetrometer Test (LIF-CPT) system in site characterization at Tinker AFB (ARA, 1993). From March to November 1992, ARA performed 112 soundings at 8 contaminated sites, including 14 CPT push tests at the Landfill 4 sludge dump. Six soil samples and two groundwater samples were collected for on-site analysis. Four soil samples and three groundwater samples were collected for off-site analysis. Soil samples were analyzed for VOCs, polyaromatic hydrocarbons (PAH), and metals. Groundwater samples were analyzed for VOCs.

2.3 Current Regulatory Status

The IRP has been ongoing at Tinker AFB since the early 1980s. IRP studies on the Base were conducted according to IRP guidance, which is essentially the same as EPA's guidance for conducting RI/FS under CERCLA. All investigation and removal actions have been closely monitored and approved by the EPA.

Since receiving the Hazardous Waste Management Permit on July 1, 1991, many of the IRP sites have come under the jurisdiction of the RCRA permits branch of EPA. As such, they have been identified as SWMUs; however, a large amount of work has already been performed at most of these sites under the IRP. Additional investigation at the SWMUs will be performed under the IRP.

3.0 Environmental Setting

3.1 Topography and Drainage

3.1.1 Topography

Regional/Tinker AFB. The topography of Oklahoma City and surrounding area varies from generally level to gently rolling in appearance. Local relief is primarily the result of dissection by erosional activity or stream channel development. At Oklahoma City, surface elevations are typically in the range of 1,070 to 1,400 feet mean sea level (msl). At Tinker AFB, ground surface elevations vary from 1,190 feet msl near the northwest corner where Crutcho Creek intersects the Base boundary to approximately 1,320 feet msl at Area D (EID).

Site. Landfill 4 is located in the southwest corner of Tinker AFB. Elevations at Landfill 4 ranged from 1,251 feet msl at boring L4-6 located on the eastern edge of the landfill to 1,255 feet msl at boring L4-4 on the southern boundary of the landfill. At boring L4-9, located on the western edge of Landfill 4, the elevation was reported to be 1,251 feet msl.

3.1.2 Surface Drainage

Regional/Tinker AFB. Drainage of Tinker AFB land areas is accomplished by overland flow of runoff to diversion structures and then to area surface streams, which flow intermittently. The northeast portion of the Base is drained primarily by unnamed tributaries of Soldier Creek, which is itself a tributary of Crutcho Creek. The north and west sections of the Base, including the main instrument runway, drain to Crutcho Creek, a tributary of the North Canadian River. Two small unnamed intermittent streams crossing installation boundaries south of the main instrument runway generally do not receive significant quantities of Base runoff due to site grading designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

Site. Most of the surface water runoff from Landfill 4 drains into the ditches along Patrol Road and Landfill Road, and then into Crutcho Creek, north of Landfills 1 through 4.

3.2 Geology

3.2.1 Regional/Tinker AFB Geology

Tinker AFB is located within the Central Redland Plain Section of the Central Lowland physiographic province, which is tectonically stable. No major fault or fracture zones have been mapped near Tinker AFB. The major lithologic units in the area of the Base are relatively flat-lying and have a regional westward dip of about 0.0076 foot per foot (ft/ft) (Bingham and Moore, 1975).

Geologic formations that underlie Tinker AFB include, from oldest to youngest, the Wellington Formation, Garber Sandstone, and the Hennessey Group; all are Permian in age.

All geologic units immediately underlying Tinker AFB are sedimentary in origin. The Garber Sandstone and Wellington Formation are commonly referred to as the Garber-Wellington Formation due to strong lithologic similarities. These formations are characterized by fine-grained, calcareously-cemented sandstones interbedded with shale. The Hennessey Group consists of the Fairmont Shale and the Kingman Siltstone. It overlies the Garber-Wellington Formation along the eastern portion of Cleveland and Oklahoma counties. Quaternary alluvium is found in many undisturbed streambeds and channels located within the area.

Stratigraphy. Tinker AFB lies atop a sedimentary rock column composed of strata that ranges in age from Cambrian to Permian above a Precambrian igneous basement. Quaternary alluvium and terrace deposits can be found overlying bedrock in and near present-day stream valleys. At Tinker AFB, Quaternary deposits consist of unconsolidated weathered bedrock, fill material, wind-blown sand, and interfingering lenses of sand, silt, clay, and gravel of fluvial origin. The terrace deposits are exposed where stream valleys have downcut through older strata and have left them topographically above present-day deposits. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

Subsurface (bedrock) geologic units which outcrop at Tinker AFB and are important to understanding groundwater and contaminant concerns at the Base consist of, in descending order, the Hennessey Group, the Garber Sandstone, and the Wellington Formation (Table 3-1). These bedrock units were deposited during the Permian Age (230 to 280 million years ago) and are typical of redbed deposits formed during that period. They are composed of a conformable sequence of sandstones, siltstones, and shales. Individual beds are lenticular and vary in thickness over short horizontal distances. Because lithologies are similar and because

Table 3-1

Major Geologic Units in the Vicinity of Tinker AFB (Modified from Wood and Burton, 1968)

(Page 1 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
QUATERNARY	PLEISTOCENE AND RECENT	Alluvium	0-70	Unconsolidated and interfingering lenses of sand, silt, clay, and gravel in the flood plains and channels of stream	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines.
		Terrace deposits	0-100	Unconsolidated and interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above the flood plains of the principal streams.	Moderately permeable. Locally above the water table and not saturated. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

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Table 3-1

(Page 2 of 2)

System	Series	Stratigraphic Unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
PERMIAN	LOWER PERMIAN	Hennessey Group (includes Kingman Siltstone and Fairmont Shale)	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places water contains large amounts of sulfate.
		Garber Sandstone	500±	Deep-red clay to reddish-orange, massive and cross-bedded fine-grained sandstone interbedded and interfingered with red shale and siltstone	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
		Wellington Formation	500±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

of a lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are often informally lumped together as the Garber-Wellington Formation. Together, they are about 900 feet thick at Tinker AFB. The interconnected, lenticular nature of sandstones within the sequence forms complex pathways for groundwater movement.

The surficial geology of the north section of the Base is dominated by the Garber Sandstone, which outcrops across a board area of Oklahoma County. Generally, the Garber outcrop is covered by a veneer of soil and/or alluvium up to 20 feet thick. To the south, the Garber Sandstone is overlain by outcropping strata of the Hennessey Group, including the Kingman Siltstone and the Fairmont Shale (Bingham and Moore, 1975). Drilling information obtained as a result of geotechnical investigations and monitoring well installation confirms the presence of these units.

Depositional Environment. The Permian-age strata presently exposed at the surface in central Oklahoma were deposited along a low-lying north-south oriented coastline. Land features included meandering to braided sediment-loaded streams that flowed generally westward from highlands to the east (ancestral Ozarks). Sand dunes were common, as were cut-off stream segments that rapidly evaporated. The climate was arid and vegetation sparse. Off shore the sea was shallow and deepened gradually to the west. The shoreline's position varied over a wide range. Isolated evaporitic basins frequently formed as the shoreline shifted.

Across Oklahoma, this depositional environment resulted in an interfingering collage of fluviatile and wind-blown sands, clays, shallow marine shales, and evaporite deposits. The overloaded streams and evaporitic basins acted as sumps for heavy metals such as iron, chromium, lead, and barium. Oxidation of iron in the arid climate resulted in the reddish color of many of the sediments. Erosion and chemical breakdown of granitic rocks from the highlands resulted in extensive clay deposits. Evaporite minerals such as anhydrite ($CaSO_4$), barite ($BaSO_4$), and gypsum ($CaSO_4 \bullet 2H_2O$) are common.

Around Tinker AFB, the Hennessey Group represents deposition in a tidal flat environment cut by shallow, narrow channels. The Hennessey Group is comprised predominantly of red shales which contain thin beds of sandstone (less than 10 feet thick) and siltstone. In outcrop, "mudball" conglomerates, burrow surfaces, and desiccation cracks are recognized. These units outcrop over roughly the southern half of the Base, thickening to approximately 70 feet in the southwest from their erosional edge (zero thickness) across the central part of Tinker AFB.

In contrast, the Garber Sandstone and the Wellington Formation around Tinker AFB consist of an irregularly-interbedded system of lenticular sandstones, siltstones, and shales deposited either in meandering streams in the upper reaches of a delta or in a braided stream environment. Outcrop units north of Tinker AFB exhibit many small to medium channels with cut and fill geometries consistent with a stream setting. Sandstones are typically cross-bedded. Individual beds range in thickness from a few inches to approximately 50 feet and appear massive, but thicker units are often formed from a series of "stacked" thinner beds. Geophysical and lithologic well logs indicate that from 65 to 75 percent of the Garber Sandstone and the Wellington Formation are composed of sandstone at Tinker AFB. The percentage of sandstone in the section decreases to the north, south, and west of the Base. These sandstones are typically fine to very fine grained, friable, and poorly cemented. However, where sandstone is cemented by red muds or by secondary carbonate or iron cements, local thin "hard" intervals exist along disconformities at the base of sandstone beds. Shales are described as ranging from clayey to sandy, are generally discontinuous, and range in thickness from a few inches to approximately 40 feet.

Stratigraphic Correlation. Correlation of geologic units is difficult due to the discontinuous nature of the sandstone and shale beds. However, cross-sections (Figure 3-1) demonstrate that two stratigraphic intervals can be correlated over large sections of the Base in the conceptual model. These intervals are represented on geologic cross-sections A-A' and B-B' (Figures 3-2 and 3-3). Section A-A' is roughly a dip section and B-B' is approximately a strike section. The first correlatable interval is marked by the base of the Hennessey Group and the first sandstone at the top of the Garber Sandstone. This interval is mappable over the southern half of Tinker AFB. The second interval consists of a shale zone within the Garber Sandstone which, in places, is comprised of a single shale layer and, in other places, of multiple shale layers. This interval is more continuous than other shale intervals and in cross-sections appears mappable over a large part of the Base. It is extrapolated under the central portion of Tinker AFB where little well controls exists.

Structure. Tinker AFB lies within a tectonically stable area; no major near-surface faults or fracture zones have been mapped near the Base. Most of the consolidated rock units of the Oklahoma City area dip westward at a low angle. A regional dip of 0.0057 to 0.0076 ft/ft in

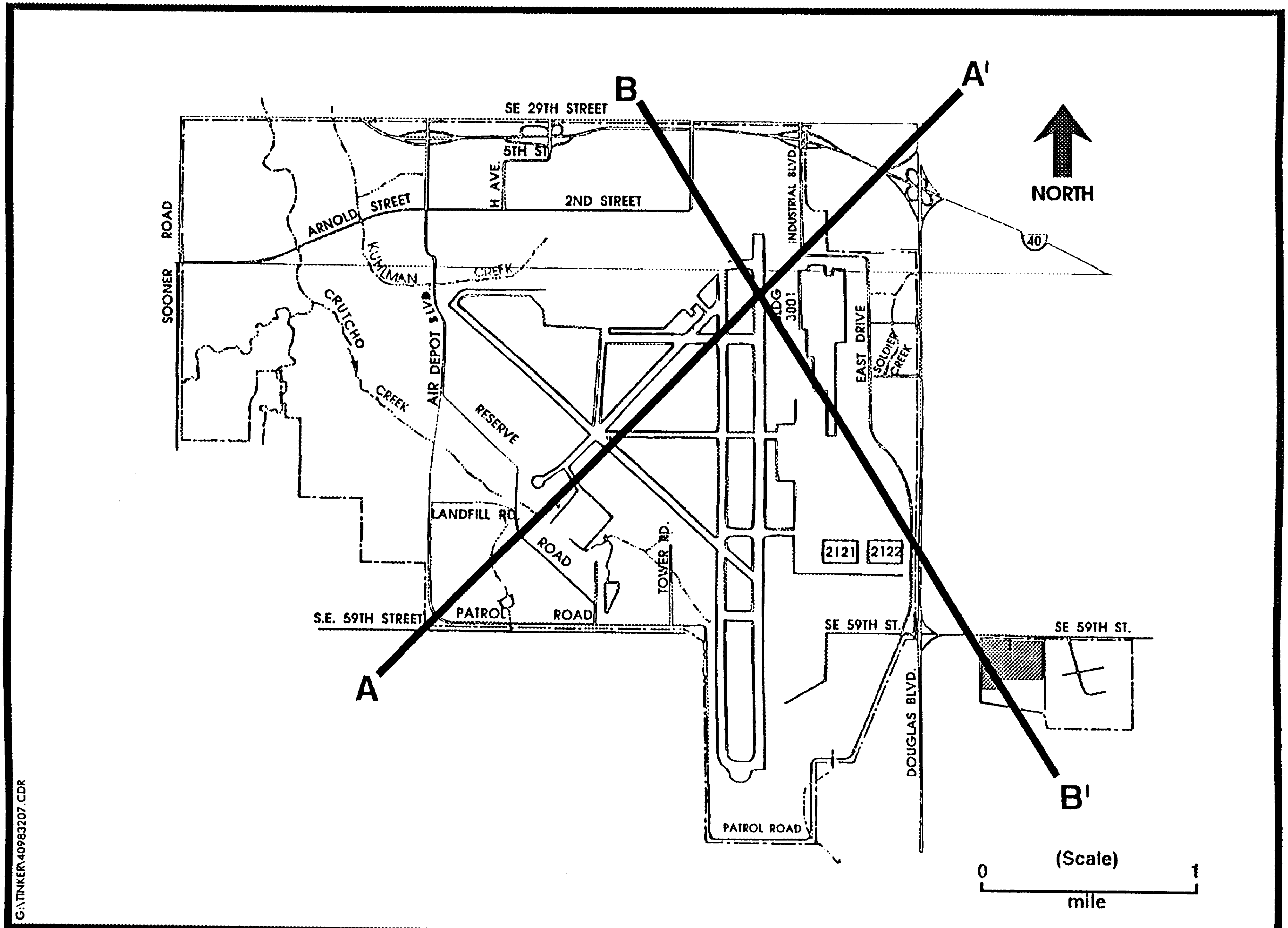

FIGURE 3-1 TINKER AFB GEOLOGIC CROSS SECTION LOCATION MAP

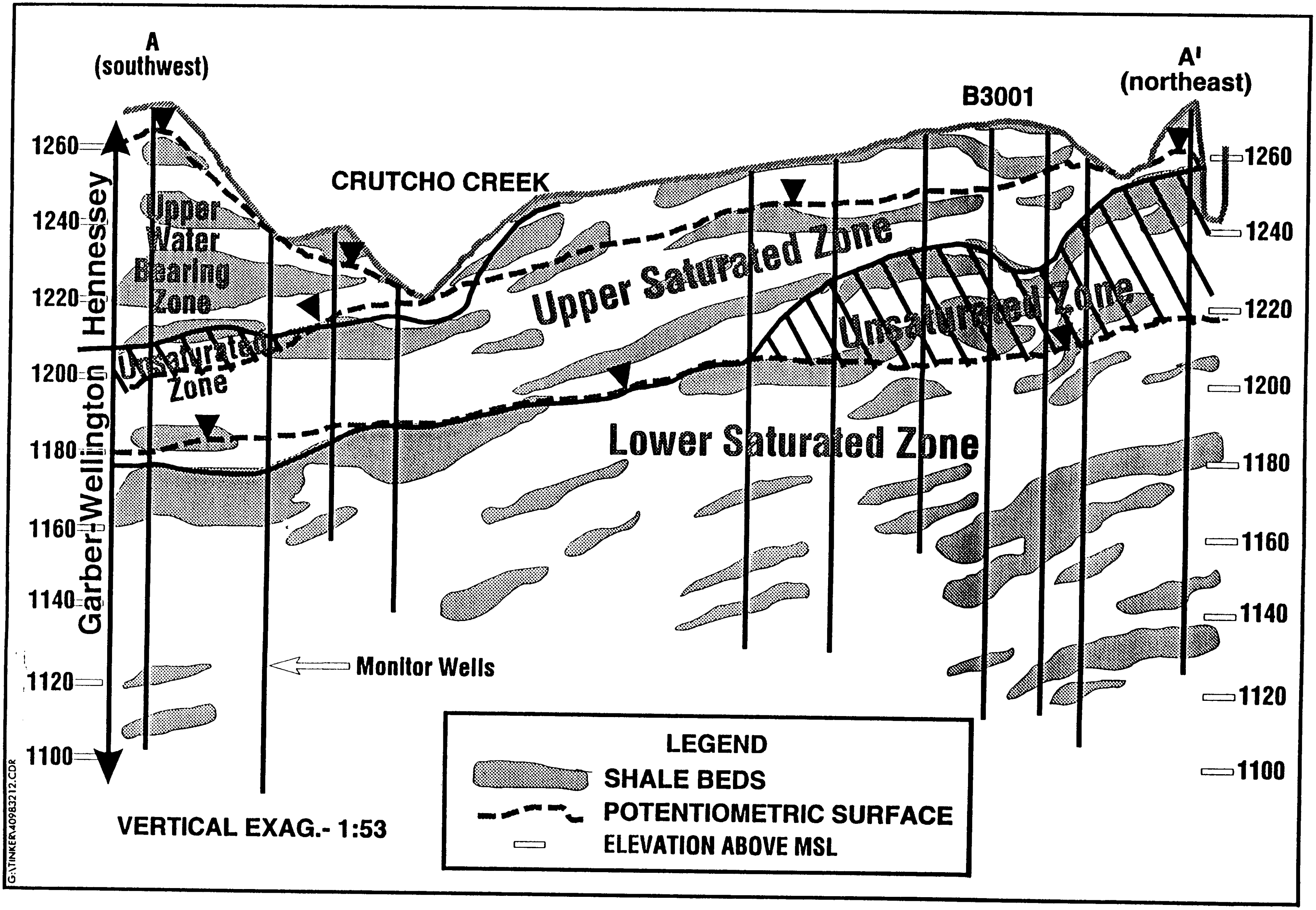

FIGURE 3-2 TINKER AFB GEOLOGIC CROSS SECTION A-A'

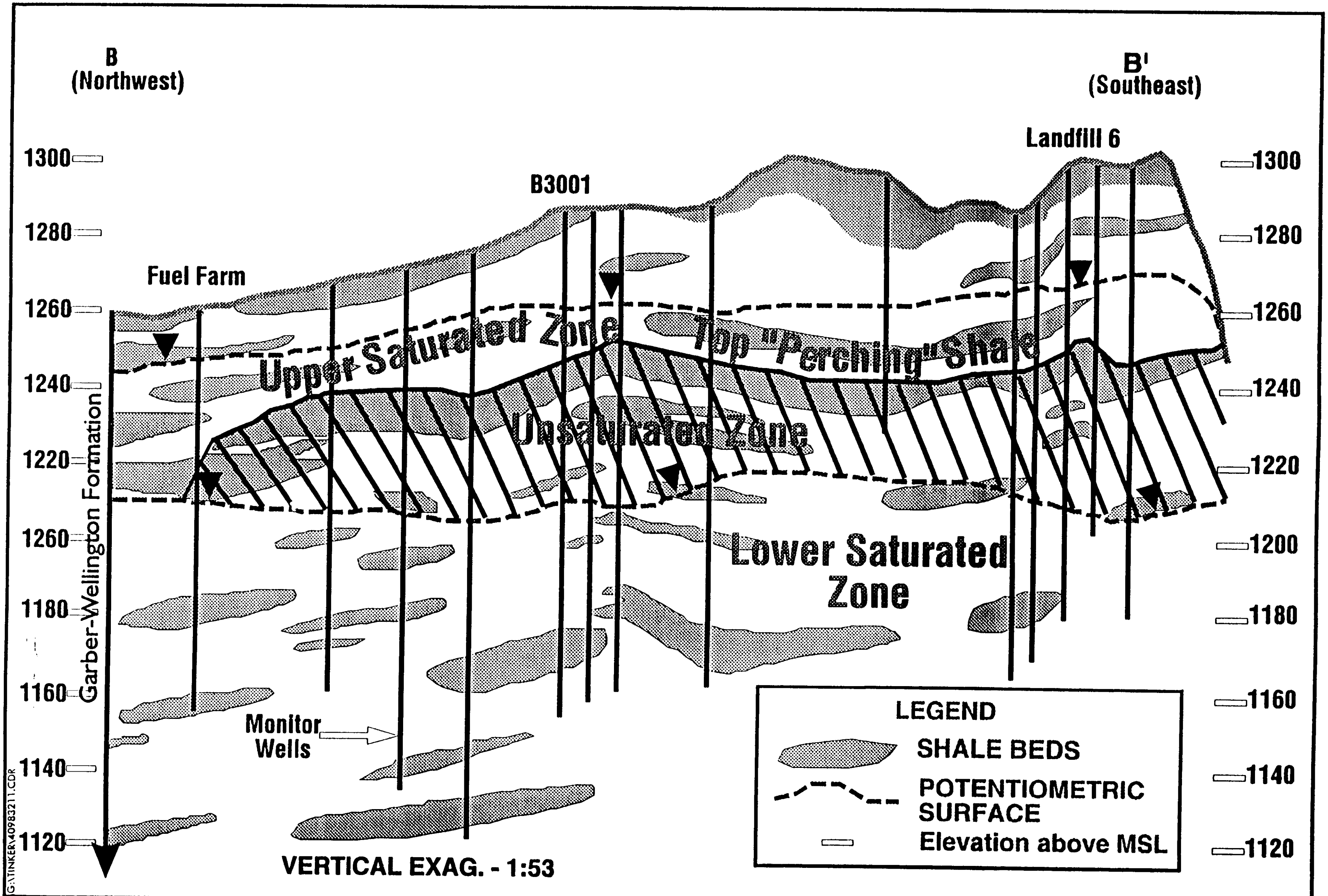

FIGURE 3-3 TINKER AFB GEOLOGIC CROSS SECTION B-B'

a generally westward direction is supported by stratigraphic correlation on geologic cross-sections at Tinker AFB. Bedrock units strike slightly west of north.

Although Tinker AFB lies in a tectonically stable area, regional dips are interrupted by buried structural features located west of the Base. A published east-to-west generalized geologic cross-section, which includes Tinker AFB, supports the existence of a northwest-trending structural trough or syncline located near the western margin of the base. The syncline is mapped adjacent to and just east of a faulted anticlinal structure located beneath the Oklahoma City Oil Field. The fault does not appear to offset Permian-age strata. There are indications that the syncline may act as a "sink" for some regional groundwater (southwest flow) at Tinker AFB before it continues to more distant discharge points.

3.2.2 Site Geology

Landfill 4 is located within the Hennessey Group, south of the contact between the Hennessey and the Garber-Wellington Formation. The Hennessey Formation outcrops over the southern half of Tinker AFB. The Hennessey thins to the north and pinches out just north of Landfills 1 through 4. It consists of reddish-brown shale with beds of siltstone and silty sandstone. Where present, the Hennessey separates the regional water table in the Garber-Wellington from the overlying perched water.

The HWBZ groundwater underneath Landfill 4 is underlain by a low-permeability shale layer. The USZ is underlain by a substantial layer of shale and siltstone from 8 to 25 feet thick.

3.3 Hydrology

3.3.1 Regional/Tinker AFB Hydrology

The most important source of potable groundwater in the Oklahoma City metropolitan area is the Central Oklahoma aquifer system. This aquifer extends under much of central Oklahoma and includes water in the Garber Sandstone and Wellington Formation, the overlying alluvium and terrace deposits, and the underlying Chase, Council Grove, and Admire Groups. The Garber Sandstone and the Wellington Formation portion of the Central Oklahoma aquifer system is commonly referred to as the "Garber-Wellington aquifer" and is considered to be a single aquifer because these units were deposited under similar conditions and because many of the best producing wells are completed in this zone. On a regional scale, the aquifer is confined above by the less permeable Hennessey Group and below by the Late Pennsylvanian Vanoss Group.

Tinker AFB lies within the limits of the Garber-Wellington Groundwater Basin. Currently, Tinker derives most of its water supply from this aquifer and supplements the supply by purchasing from the Oklahoma City Water Department. The nearby communities of Midwest City and Del City derive water supplies from both surface sources and wells tapping the aquifer. Industrial operations, individual homes, farm irrigation, and small communities not served by a municipal distribution system also depend on the Garber-Wellington aquifer. Communities presently depending upon surface supplies (such as Oklahoma City) also maintain a well system drilled into the Garber-Wellington as a standby source of water in the event of drought.

Recharge of the Garber-Wellington aquifer is accomplished principally by percolation of surface waters crossing the area of outcrop and by rainfall infiltration in this same area. Because most of Tinker AFB is located in an aquifer outcrop area, the Base is considered to be situated in a recharge zone.

According to Wood and Burton (1968) and Wickersham (1979), the quality of groundwater derived from the Garber-Wellington aquifer is generally good, although wide variations in the concentrations of some constituents are known to occur. Wells drilled to excessive depths may encounter a saline zone, generally greater than 900 feet below ground surface. Wells drilled to such depths or those accidentally encountering the saline zone are either grouted over the lowest screens or may be abandoned.

Tinker AFB presently obtains its water supplies from a distribution system comprised of 29 water wells constructed along the east and west Base boundaries and by purchase from the Oklahoma City Water Department. All Base wells are finished into the Garber-Wellington aquifer. Base wells range from 700 to 900 feet in finished depth, with yields ranging from 205 to 250 gallons per minute. The wells incorporate multiple screens, deriving water supplies from sand zones with a combined thickness from 103 to 184 feet (Wickersham, 1979).

Although the variability in the geology and the recharge system at Tinker AFB makes it difficult to predict local flow paths, Central Oklahoma aquifer water table data show that regional groundwater flow under Tinker varies from west-northwest to southwest, depending on location. This theory is supported by contoured potentiometric data from base monitoring wells which show groundwater movement in the upper and lower aquifer zones to generally follow regional dip. Measured normal to potentiometric contours, groundwater flow gradients

range from 0.0019 to 0.0057 ft/ft. However, because flow in the near-surface portions of the aquifer at Tinker AFB is strongly influenced by topography, local stream base-levels, complex subsurface geology, and location in a recharge area, both direction and magnitude of groundwater movement is highly variable. The interaction of these factors not only influences regional flow but gives rise to complicated local, often transient, flow patterns at individual sites.

As a result of ongoing environmental investigations and the approximately 450 groundwater monitoring wells installed on the Base during various investigations, a better understanding of the specific hydrological framework has emerged. The current conceptual model developed by Tinker AFB (Tinker, 1993), based on the increased understanding of the hydrological framework, has been revised from an earlier model adopted by the USACE. Previous studies reported that groundwater was divided into four water-bearing zones: the perched aquifer, the top of regional aquifer, the regional aquifer, and the producing zone. In the current model, two principal water table aquifer zones and a third less extensive zone have been identified. The third is limited to the southwest quadrant. The third aquifer zone consisted of saturated siltstone and thin sandstone beds in the Hennessey Shale and equates to the upper water bearing zone (UWBZ) described by the USACE (1993) at Landfills 1 through 4. In addition, numerous shallow, thin saturated beds of siltstone and sandstone exist throughout the Base. These are of limited areal extent and are often perched.

In the current conceptual hydrologic model, a USZ and an LSZ are recognized in the interval from ground surface to approximately 200 feet. Below this is found the producing zone from which the Base draws much of its water supply. Figure 3-4 shows the potentiometric surface for the USZ and Figure 3-5 shows the potentiometric surface for the LSZ. The USZ exists mainly under water table (unconfined) conditions, but may be partially confined locally. Conditions in the LSZ are difficult to determine due to screen placement and overly long sandpacks below the screen interval.

The USZ is found at a depth of 5 to 70 feet below ground surface and has a saturated thickness ranging from less than 1 foot at its eastern boundary to over 20 feet in places west of Building 3001. The USZ is erosionally truncated by Soldier Creek along the northeastern margin of Tinker AFB. This aquifer zone is considered to be a perched aquifer over the eastern one-third of Tinker AFB, where it is separated from the LSZ by an underlying confining shale layer and a vadose zone. The confining interval extends across the entire Base, but the vadose zone exists over the eastern one-third of this area. The available

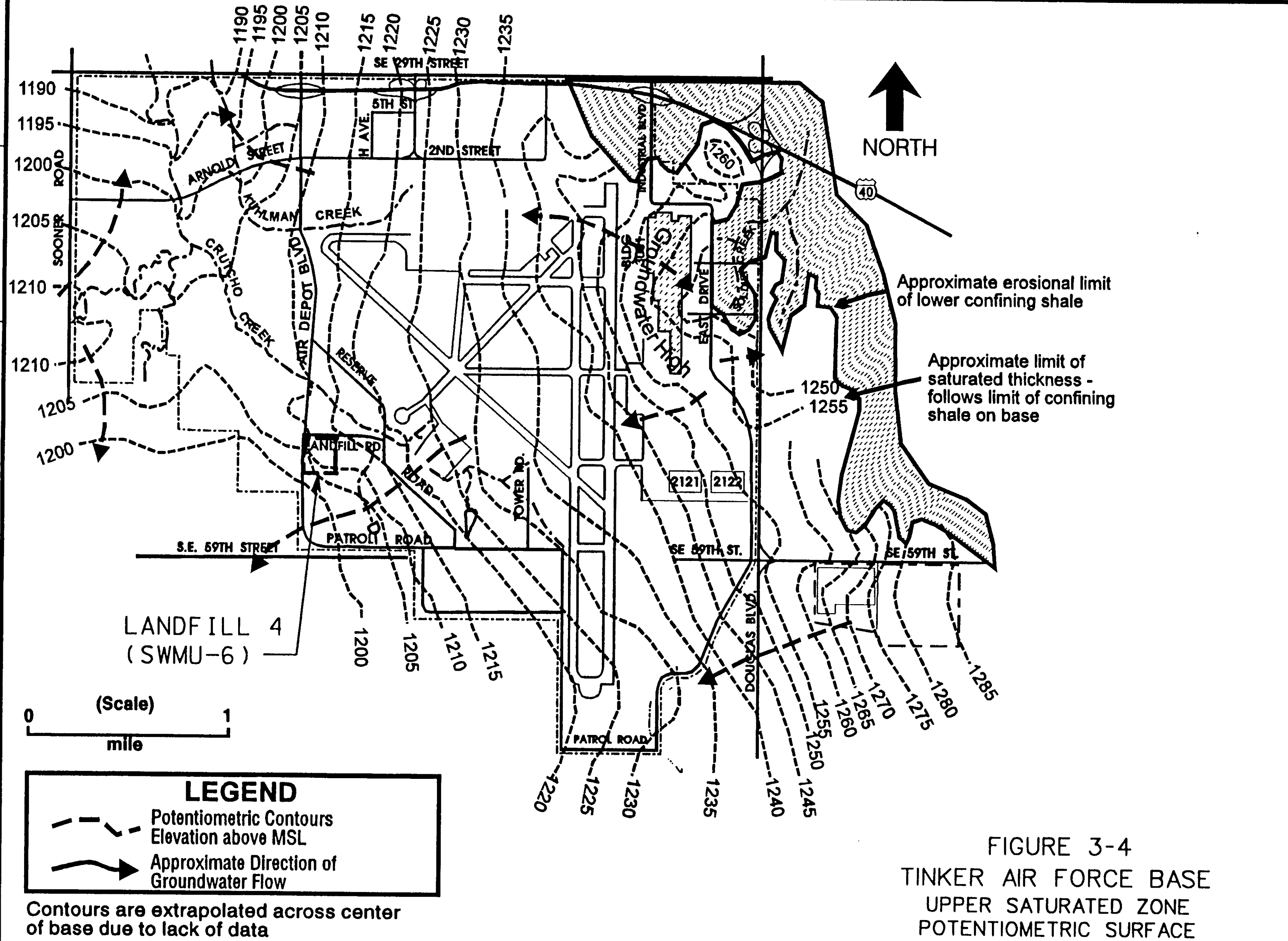

FIGURE 3-4
TINKER AIR FORCE BASE
UPPER SATURATED ZONE
POTENTIOMETRIC SURFACE

STARTING DATE: 23MAR94	DATE LAST REV.:	DRAFT. CHCK. BY:	INITIATOR: C.WALLACE	DWG. NO.:40983209C.
DRAWN BY: C.E.TUMLIN	DRAWN BY:	ENGR. CHCK. BY:	PROJ. MGR.: J.TAYLOR	PROJ. NO.:409832

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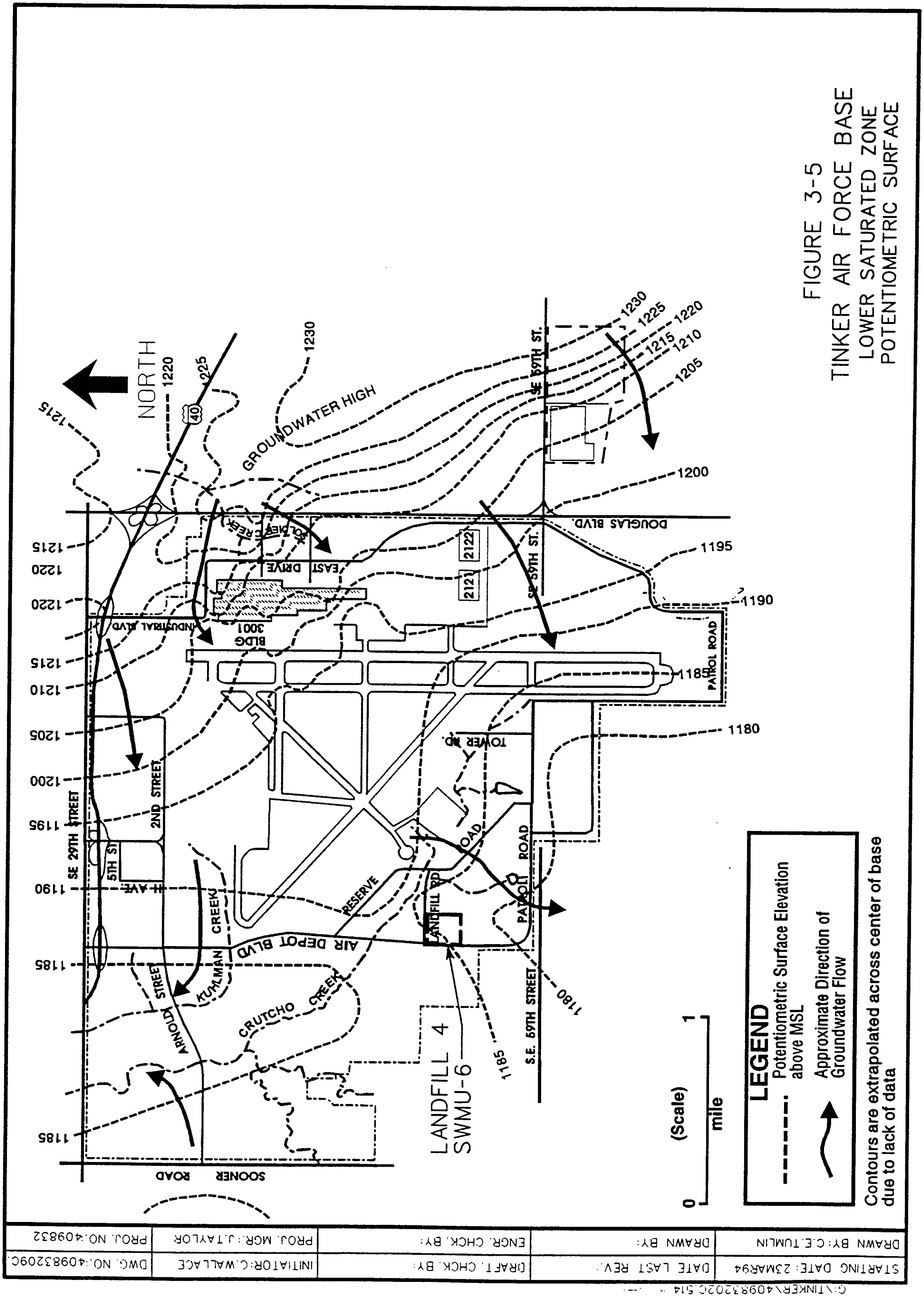

FIGURE 3-5
TINKER AIR FORCE BASE
LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE

hydrogeologic data indicate that the vadose zone does not exist west of a north-south line located approximately 500 to 1,000 feet west of the main runway; consequently, the USZ is not perched west of this line. However, based on potentiometric head data from wells screened above and below the confining shale layer, the USZ remains a discrete aquifer zone distinct from the LSZ even over the western part of the Base. In areas where several shales interfinger to form the lower confining interval rather than a single shale bed, "gaps" may occur. In general, these "gaps" are not holes in the shale, but are places where multiple shales exist that are separated by slightly more permeable strata. Hydrologic data from monitoring wells indicate that these zones allow increased downward flow of groundwater above what normally leaks through the confining layer.

The LSZ is hydraulically interconnected and can be considered one aquifer zone down to approximately 200 feet. This area includes what was referred to by the USACE (1993) as the top of regional and regional zones. Hydrogeologic data from wells screened at different depths at the same location within this zone, however, provide evidence that locally a significant vertical (downward) component of groundwater flow exists in conjunction with lateral flow. The magnitude of the vertical component is highly variable over the Base. Preliminary evidence suggests that the LSZ is hydraulically discrete from the producing zone. Due to variations in topography, the top of the lower zone is found at depths ranging from 50 to 100 feet below ground surface under the eastern parts of the Base and shallow as 30 feet to the west. Differences in potentiometric head values found at successive depths are due to a vertical (downward) component of groundwater flow in addition to lateral flow and the presence or absence of shale layers which locally confine the aquifer system. The LSZ extends east of the Base (east of Soldier Creek) beyond the limits of the USZ where it becomes the first groundwater zone encountered in off-Base wells. Because of the regional dip of bedding, groundwater gradient, and topography, the LSZ just east of the Base is generally encountered at depths less than 20 feet.

3.3.2 Site Hydrology

The groundwater beneath Landfill 4 exists in three distinct zones: the HWBZ, USZ, and LSZ. The HWBZ is a perched water bearing zone developed in the southwest quadrant of Tinker AFB in the vicinity of Landfills 1 through 4. This zone is characterized by numerous thin saturated siltstone and sandstone beds alternating with shale beds. Delineation of this zone is complicated by a complex stratigraphy of water bearing and sealing beds of limited areal extent. Due to the complex stratigraphy and limited well control, the HWBZ and USZ are considered as a single zone for the purposes of this report.

The uppermost saturated zone is the USZ. This zone, which by definition includes the HWBZ, is hydraulically connected to the water encountered in the landfill trenches and Crutcho Creek. Figure 3-4, which presents the potentiometric surface for the USZ in the Tinker AFB area, shows that groundwater flow in the vicinity of Landfill 4 is generally to the southwest.

The deepset hydrogeologic zone at the site is the LSZ. The LSZ was previously identified in the RI report for Landfills 1 through 4 as the top of the regional zone. The LSZ is composed primarily of interbedded shale, siltstone, and sandstone. The LSZ formation was encountered at depths of 50 to 70 feet below grade and extended to a maximum depth of 125 feet before encountering a lower confining unit.

The USZ and the LSZ are separated by a low permeability shale layer. This shale interval, which is part of the Hennessey Group, varies in thickness and pinches out north of Landfill Road underneath Landfill 1. The shale interval acts as the lower confining bed for the USZ and, therefore, perches the USZ. This shale interval is the second mappable layer discussed earlier under the section on stratigraphic correlation. The landfill trenches are set within and underlain by clay. The clay is a low-permeability layer, but it does not present as much of a barrier as the shale layer to the south. Average permeabilities for the clay and shale layers were reported to be 1.4×10^{-8} cm/s and 3×10^{-9} cm/s, respectively.

3.4 Soils

Three major soil types have been mapped in the Tinker AFB area and are described in Table 3-2 (U.S. Department of Agriculture [USDA], 1969). The three soil types, the Darrell-Stephenville, Renfrow-Vernon-Bethany, and Dale-Canadian-Port, consist of sandy to fine sandy loam, silt loam, and clay loam, respectively. The Darrell-Stephenville and the Renfrow-Vernon-Bethany are primarily residual soils derived from the underlying shales of the Hennessey Group. The Dale-Canadian-Port association is predominantly a stream-deposited alluvial soil restricted to stream floodplains. The thickness of the soils ranges from 12 to 60 inches. Landfill 4 lies entirely within the Renfrow-Vernon-Bethany soil association.

Table 3-2

Tinker AFB Soil Associations
(Source: USDA, 1969)

Association	Description	Thickness (in.)	Unified Classification[a]	Permeability (in./hr)
Darrell-Stephenville: loamy soils of wooded uplands	Sandy loam Sandy clay loam Soft sandstone (Garber Sandstone)	12-54	SM,ML,SC	2.0-6.30
Renfrow-Vernon-Bethany: loamy and clayey soils on prairie uplands	Silt loam - clay Clay loam Shale (Fairmont Shale)	12-60	ML,CL,MH,CH	<0.60-0.20
Dale-Canadian-Port: loamy soil on low benches near large streams	Fine sandy loam Silty clay loam Loam Clay loam	12-60	SM,ML,CL	0.05-6.30

[a]Unified classifications defined in U.S. Bureau of Reclamation, 5005-86.

4.0 Source Characterization

Landfill 4 was used for the disposal of an estimated 320,000 cubic yards of waste generated at Tinker AFB from 1961 to 1968. The landfill was used primarily for the disposal of general refuse, but drummed materials of solidified solvents and metal shavings were also disposed of in the landfill area. One specific-use sludge dump was located in the central portion of the landfill. This area was used for landfarming of sludges taken from the bottom of petroleum and solvent storage tanks. The sludges were spread on top of the landfill and periodically disked to aerate the soil/sludge mixture to promote biodegradation.

The landfill was constructed by excavating a series of 35 to 40-foot-wide by 25-foot-deep trenches, oriented east to west across the site. Waste was deposited in the trenches and covered daily with several inches of excavated, native soil. A final cover of 3 to 4 feet of soil was placed over the completed trench cells.

Borings at the site revealed a mixed layer of trash just under the landfill surface composed primarily of wood, metal, paper, rubber, plastic, asphalt, and cement. Gauze bandages were also found in the trench waste material. This may indicate that Landfill 4 received waste from the on-Base hospital.

In 1987, six borings were drilled into the former landfill trenches. Soil and waste samples were collected by three methods: split-spoon samplers, Shelby tubes, and composite samples. During an investigation in 1989 to define the southern boundary of Landfills 2 and 4, seven additional borings were drilled at the southern periphery of Landfill 4. Geologic logs for all the borings are contained in Appendix J of the USACE draft-final RI report for Landfills 1 through 4 (USACE, 1993). Table 4-1 presents the waste description and depth of occurrence for each boring advanced into the landfill. Waste materials were encountered in only the six 1987 borings.

During the 1987 soils investigation, two surface and six subsurface soil samples were collected and analyzed for VOCs, SVOCs, metals, pesticides, PCBs, and parameters such as TOC, cyanide, pH, conductivity, and phenols. VOCs, SVOCs, and metals were detected in landfill soils.

Groundwater was encountered within the landfill trenches during the 1987 soil investigations. The trench water was sampled to determine the quality of the HWBZ groundwater within the

Table 4-1

Waste
SWMU-6, Landfill 4, Tinker AFB

Boring No.	Waste Description	Depth (feet)
L4-1	Refuse, paper, plastic, rags, wire, glass	2.0-18.0
L4-2	Refuse, black material	6.0-16.5
L4-3	Refuse, black material	8.0-16.5
L4-4	Refuse, paper, rags, scrap wood	6.0-23.0
L4-5	Refuse, paper, glass, ceramic shards	5.0-16.0
L4-6	Refuse, paper, plastic, wire, metal scraps, rubber hose	4.0-24.5

Reference: U.S. Army Corps of Engineers (USACE), Draft-Final RI Report, Landfills 1 through 4, October 1993.

trenches. The groundwater was found to be contaminated through contact with the waste material deposited in the trenches. The nature and extent of soil and groundwater contamination is discussed in Chapter 5.0, Contaminant Characterization.

5.0 Contaminant Characterization

Through several phases of investigation, soils, soil gas, surface water, and groundwater have been sampled for contaminants potentially introduced into the environment as a result of past waste disposal practices at Landfill 4. Analytical results of samples taken in and around Landfill 4 indicate the presence of elevated concentrations of VOCs, SVOCs, and metals. Contaminants have been detected in soils and groundwater in the area of the former disposal trenches, in soil gas with the landfill vadose zone, in surface leachate from the west bank of the landfill, and to a limited degree, in groundwater downgradient of the landfill.

Establishment of Surficial Soil Background Concentrations. Background soil concentrations for trace metals (Table 5-1) were determined based on a study performed by the USGS (1991). The study area was confined to approximately four counties in central Oklahoma. Tinker AFB lies at the approximate center of this area. A total of 293 B-horizon soil samples were collected throughout this area. Soil samples were collected at the top of the B-horizon, which was usually 20-30 centimeters below the surface but ranged from 3 to 50 centimeters below the surface. For site-specific analytes for which the USGS offered no background value, the analyte was compared to an applicable action level.

The use of B-horizon soil as selected by the USGS for metals background concentrations in soil is conservative in that the soil sampled does not reflect all possible anthropogenic influences. Most of the samples were obtained from hill crests and well-drained areas in pasture and forested land, well away from roadways to minimize contamination from vehicular emissions (i.e., nearly "Pristine" areas). Trace metal inputs to the study site soils on Base will come from anthropogenic sources outside of the study area, in addition to those sources related to disposal activities or operations within the confines of the study site. Therefore, responsibility may be taken for more trace metal impacts than are actually attributable to a given site.

An additional level of conservatism was added in the manner in which the site-specific metals concentrations were compared to the background levels. Typically, the environmental concentrations of trace metals at study sites are represented by the arithmetic upper 95th confidence interval on the mean of a normal distribution. This upper 95th confidence interval value is then compared to the background values. The intent of this typical approach is to estimate a Reasonable Maximum Exposure case (i.e., well above the average case) that is still within the range of possible exposures.

Table 5-1

Background Concentrations of Trace Metals in Surface Soils[a] SWMU-6, Landfill 4, Tinker AFB

(Page 1 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Concentration in %			
Aluminum	0.005	0.38	8.9
Cadmium	0.005	0.01	9.4
Iron	0.005	0.18	5.8
Magnesium	0.005	0.02	5.3
Phosphorous	0.005	0.06	0.019
Potassium	0.05	0.1	2.4
Sodium	0.005	0.02	0.99
Titanium	0.005	0.04	0.42
Concentrations in ppm			
Arsenic	0.1	0.6	21
Barium	1	47	6400
Beryllium	1	<1	3
Bismuth	10	<DL[b]	<DL
Cadmium	2	<DL	<DL
Cerium	4	14	110
Chromium	1	5	110
Cobalt	1	<1	27
Copper	1	<1	59
Europium	2	---[c]	---
Gallium	4	<4	23
Gold	8	<DL	<DL
Holmium	4	<DL	<DL
Lanthanum	2	7	51
Lead	4	<4	27
Lithium	2	5	100

Table 5-1

(Page 2 of 2)

Analyte	Lower Detection Limit	Background Concentration Range	
		Minimum Value	Maximum Value
Manganese	10	24	3400
Molybdenum	2	<DL	<DL
Neodymium	4	6	47
Nickel	2	<2	61
Niobium	4	<4	16
Scandium	2	<2	15
Selenium	0.1	<0.1	1.2
Silver	2	<DL	<DL
Strontium	2	13	300
Tantalum	40	<DL	<DL
Thorium	1	<1.40	15.00
Tin	10	<DL	<DL
Uranium	0.1	0.650	6.400
Vanadium	2	5	220
Ytterbium	1	<1	3
Yttrium	2	3	43
Zinc	2	3	79

[a]All B-horizon soil samples (293) from USGS, 1991.
[b]All concentrations below the lower limits of determination.
[c]Insufficient or no data.

To expedite this comparison and establish greater conservatism, the maximum concentration found at the site of concern, rather than the upper 95th confidence interval value, was compared to the USGS background values. If the environmental concentration of a particular analyte was below or within the minimum-maximum range of the USGS background concentrations, that analyte was considered to be naturally occurring and of no further concern to this investigation. Given this doubly conservative approach, site-specific metals concentrations would have to significantly exceed the USGS background levels and be attributable to operations at the site before they would be considered a contaminant of concern.

The numerical comparison of site-specific metals concentrations to the USGS background concentrations is presented in the following sections.

Soils. During the RI, 2 surface and 6 subsurface soil samples were collected at the former trench sites and sludge dump at Landfill 4. The soil samples were analyzed for VOCs, SVOCs, metals, pesticides, PCBs, cyanide, and indicator parameters such as TOC, pH, conductivity, and phenols. VOCs, SVOCs, and metals were detected in the landfill soils. A summary of detected constituents from trench soil samples is provided in Table 5-2.

In 1992, ARA was contracted to perform a LIF-CPT study at Tinker AFB. As a part of this study, 14 CPT push sites were completed in the area of the sludge dump at Landfill 4. No LIF profiling was performed at the landfill. During the study, ten soil samples were collected and analyzed for VOCs, PAHs, and metals. Six of the soil samples were analyzed on site, with the remaining four samples submitted to an off-site lab for analysis. Table 5-3 presents a summary of the analytical results for these soil samples.

Soil Gas. In 1990, Tracer Research Corporation conducted a shallow SGI at Landfill 4. Samples were collected along grid points on 200 foot centers with the exception of a subsite survey at the sludge dump that was sampled on 50 foot intervals. Forty-seven soil gas samples were collected in and around the landfill, including eighteen samples in the area of the sludge dump. The samples were collected at depths of 1 to 6 feet below grade. Sampling locations are presented in Figures 1 and 3 of the SGI report (Tracer, 1990). Soil gas samples were analyzed for the following target compounds:

- 1,1,1-trichloroethane
- Trichloroethene
- Tetrachloroethene

Table 5-2

Summary of Analytical Results[a]
1987 Soil Sampling
SWMU-6, Landfill 4, Tinker AFB

(Page 1 of 3)

Boring Number	L4-1	L4-2	L4-3	L4-4	L4-5	L4-6	4-1-5	4-5-1
Depth (ft)	2-18	6-16.5	8-16.5	6-23	5-16	4-24.5	Surface	Surface
Sample Number	7-176	7-177	7-178	7-179	7-189	7-180	1-170	1-171
Sample Date	2/87	2/87	2/87	2/87	2/87	2/87	2/87	2/87
Volatiles (µg/kg)								
Acetone	490	460	1400	1200	23000	1000	<15	<14
2-Butanone	<15	130	800	150	200000	10	<15	<14
Carbon disulfide	<7	38	<7	<7	<2765	<7	<7	<7
Chlorobenzene	13	160	300	21	<2765	45	<7	<7
Ethyl benzene	57	<7	59	110	<2765	57	<7	<7
2-Hexanone	190	110	490	79	5600	5 J	<15	<14
Methylene chloride	14	40	41	35	<2765	51	8	7
4-Methyl-2-pentanone	<15	9 J	21	19	5530 J	<14	<15	<14
Styrene	<7	<7	<7	16	<2765	9	<7	<7
Tetrachloroethene	<7	<7	11	9	<2765	<7	<7	<7
Toluene	<7	120	170	440	1830 J	25	<7	<7
Total xylenes	66	380	160	310	3400	190	<7	11

KN/1256/SWMU6/SWMU6.5-2/04-07-94/D5 7:48am

Table 5-2

(Page 2 of 3)

Boring Number	L4-1	L4-2	L4-3	L4-4	L4-5	L4-6	4-1-5	4-5-1
Depth (ft)	2-18	6-16.5	8-16.5	6-23	5-16	4-24.5	Surface	Surface
Sample Number	7-176	7-177	7-178	7-179	7-189	7-180	1-170	1-171
Sample Date	2/87	2/87	2/87	2/87	2/87	2/87	2/87	2/87
Semivolatiles (µg/kg)								
Bis(2-ethylhexyl)phthalate	1900 J	1900 J	<4400	940	4500	5100	<460	<460
Diethyl phthalate	1300 J	<4400	5200	210 J	5100	<4800	<460	180 J
Di-n-butyl phthalate	<5000	<4400	<4400	<450	2600	<4800	<460	<460
4-Methylphenol	<5000	<4400	<4400	750	<2200	<4800	<460	<460
Phenol	<5000	<4400	<4400	<450	5500	<4800	<460	<460
Metals (mg/kg)								
Arsenic	<1.0	1	1.2	3.6	1	1	3.2	1.1
Barium	350	150	370	4500	480	150	700	480
Cadmium	8.2	520	40	1.6	5.8	8	2.4	1.5
Chromium	25	120	640	11	18	16	12	9.5
Lead	36	150	75	9.6	61	56	36	29
Mercury	0.59	<0.1	0.28	0.14	0.72	0.52	<0.1	<0.1
Nickel	15	330	100	21	21	15	22	12
Silver	2.1	27	8.6	1.1	12	1.2	1.4	1
Zinc	120	83	210	41	330	140	110	62

KN/1256/SWMU6/SWMU6.5-2/04-07-94/D5 7:48am

Table 5-2

(Page 3 of 3)

Boring Number	L4-1	L4-2	L4-3	L4-4	L4-5	L4-6	4-1-5	4-5-1
Depth (ft)	2-18	6-16.5	8-16.5	6-23	5-16	4-24.5	Surface	Surface
Sample Number	7-176	7-177	7-178	7-179	7-189	7-180	1-170	1-171
Sample Date	2/87	2/87	2/87	2/87	2/87	2/87	2/87	2/87
Indicators (mg/kg)								
TOC	4,400	22400	6200	1700	26000	7100	10000	8200
Cyanide	0.54	2.9	0.66	<0.2	0.32	<0.2	0.38	<0.2
pH (s.u.)	7.16	7.7	6.86	7.20	6.86	7	7.34	7.35
Conductivity (µmhos/cm)	2800	3100	3100	2100	1500	1700	1600	2800
Phenols (µg/kg)	NT	NT	NT	NT	35000	NT	371	350

[a]Data from Landfills 1-4 RI Report (USACE, 1993).
NT = Compound not tested for.
B = Compound also present in blank.
J = Compound present below laboratory detection limits.

Table 5-3

Summary of Analytical Results for Soil[a]
1992 Cone Penetrometer Study
SWMU-6, Landfill 4, Tinker AFB

CPT Push Site Sample Depth (ft) Sample Date	LF4-05 3-4.6 10/92	LF4-06 2-9.6 10/92	LF4-06 12-13 10/92	LF4-06 13-14.6 10/92	LF4-10 8-9.6 10/92
Volatiles (μg/kg)					
Chlorobenzene	<5	140	NT	<5	<5
Ethyl benzene	<5	80	NT	<5	<5
Methylene chloride	40[b]	46[b]	43	43[b]	45[b]
1,1,1-Trichloroethane	126[b]	22[b]	<5	<5	<5
Xylenes	<10	150	<20	<10	<10
Semivolatiles (μg/kg)					
Benzo(a)anthracene	<330	3400	NT	NT	<330
Benzo(a)pyrene	<330	2200	NT	NT	<330
Benzo(b)fluoranthene	<330	8300	NT	NT	<330
Benzo(k)fluoranthene	<330	1000	NT	NT	<330
Chrysene	<330	5800	NT	NT	<330
Fluoranthene	<330	930	NT	NT	<330
Phenanthrene	<330	2100	NT	NT	<330
Pyrene	<330	2500	NT	NT	<330
Metals (mg/kg)					
Arsenic	72	<1.0	NT	<1.0	<1.0
Barium	360	380	NT	630	640
Cadmium	47	17	NT	2.4	25
Chromium	57	48	NT	38	200
Mercury	0.2	0.1	NT	<0.001	<0.001
Nickel	42	38	NT	29	41
Lead	1400	340	NT	8.1	23
Zinc	310	380	NT	54	40
Indicators (mg/kg)					
TPH	8000	11,000	NT	NT	54

[a]Data from Tables 25 and 27 of Laser-Induced Fluorescence-Electronic Cone Penetrometer Investigation Report, Volume II (ARA, 1993).
[b]Result reported is from on-site analysis. The off-site analysis did not detect this compound.

- Methane
- Benzene
- Toluene
- Ethyl benzene
- Xylenes
- Total hydrocarbons

Analytical results from the SGI are presented in Table 5-4.

Surface Water. During a 1979 study conducted by Tinker AFB Bioenvironmental Engineering, samples of landfill surface leachate and perimeter drainage ditch waters were collected for analysis. The 1979 leachate samples were analyzed for metals and indicator parameters such as chemical oxygen demand (COD), oil and grease, and phenols. The analytical data from this investigation revealed high concentrations of COD, oil and grease, phenols, and heavy metals (ES, 1982). The results of this sampling effort are presented in Table 5-5.

In 1984, Radian Corporation collected a surface leachate sample from the west bank of the landfill. The 1984 leachate samples were analyzed for metals and indicator parameters such as oil and grease, phenols, TOC, and TOX. The leachate sample was typical of sanitary landfill leachate, but with a TOX value of 1500 μg/L, suggesting the presence of chlorinated organic compounds. The analytical results from this sample are also presented in Table 5-5.

In 1987, the USACE collected two surface leachate samples from locations L4-7 and L4-8 shown on Drawing No. 1 in the RI report (USACE, 1993). The samples were analyzed for VOCs and SVOCs. Analytical results for these samples are presented in Table 5-5.

Groundwater. Groundwater in the vicinity of Landfill 4 was characterized by collecting groundwater samples from soil borings within the landfill and from selected groundwater monitoring wells in the vicinity of the landfill. Seven groundwater samples were collected from five soil borings to characterize the contamination in the USZ in the area of the former landfill trenches and sludge dump. Table 5-6 presents a summary of the trench groundwater data.

Table 5-4

Summary of Soil Gas Investigation Results[a]
SWMU-6, Landfill 4, Tinker AFB

Sample	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	TPH (µg/L)
03/21/90									
AIR	0.0005	<0.0002	<0.00003	1	<0.02	<0.02	<0.03	<0.03	<0.02
L4/SG-1-1'	0.0006	<0.0002	0.0008	50	<0.2	0.05	<0.03	<0.03	0.05
L4/SG-2-2'	0.0005	<0.0002	0.0004	2	<0.02	<0.02	<0.03	<0.03	<0.02
L4/SG-3-1'	0.0006	<0.0002	0.0004	10	<0.02	30	<0.03	<0.03	120
L4/SG-7-2'	0.0005	<0.0002	0.0004	1	<0.02	0.6	<0.03	<0.03	4
L4/SG-8-2'	0.0004	<0.0002	0.0004	2	<0.02	<0.02	<0.03	<0.03	<0.02
L4/SG-13-2'	0.0006	<0.0002	0.0006	690	<0.02	<0.02	<0.03	<0.03	<0.02
L4/SG-17-2'	0.0005	<0.0002	0.0001	90	<0.02	<0.02	<0.03	<0.03	<0.02
L4/SG-16-2'	0.0004	0.02	0.001	8800	<0.02	<0.02	<0.03	<0.03	2
L4/SG-15-2'	0.0006	0.04	0.006	11000	<0.2	<0.2	<0.3	<0.3	<0.2
L4/SG-24-2'	0.0008	<0.0002	0.0008	60	<0.1	<0.1	<0.1	<0.2	<0.1
AIR	0.0009	<0.0002	0.0004	1	<0.02	<0.02	<0.03	<0.03	<0.02
03/22/90									
AIR	0.002	<0.0002	0.0009	2	<0.02	<0.03	<0.03	<0.03	<0.03
L4/SG-11-2'	0.0008	0.002	0.001	600	<0.02	<0.03	<0.03	<0.03	10

Table 5-4

(Page 2 of 4)

Sample	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	TPH (µg/L)
03/22/90 (Continued)									
L4/SG-10-1'	0.0006	<0.0002	0.0008	30	<0.02	<0.03	<0.03	<0.03	0.5
L4/SG-19-2'	1	0.04	0.02	4500	<0.02	<0.03	<0.03	<0.03	9
L4/SG-18-2'	0.0007	<0.0002	0.0009	730	<0.02	<0.03	<0.03	<0.03	<0.03
L4/SG-20-2'	0.008	0.05	0.008	5000	<0.02	<0.03	<0.03	<0.03	15
L4/SG-21-2'	0.06	0.02	0.002	5500	<0.02	<0.03	<0.03	<0.03	30
L4/SG-22-2'	0.001	0.02	0.006	1800	<0.02	<0.03	<0.03	<0.03	50
L4/SG-23-2'	0.0005	0.02	0.006	2100	<0.02	<0.03	<0.03	<0.03	100
SG-12-1'	0.0004	<0.0002	<0.00004	10	<0.02	<0.03	<0.03	<0.03	<0.03
03/24/90									
AIR	0.0006	<0.0002	0.0002	2	<0.02	<0.03	<0.03	<0.03	<0.03
SG-29-1'	0.0004	<0.0002	0.00009	3	<0.02	<0.03	<0.03	<0.03	2
SG-20-2'	0.007	0.04	0.004	10000	<0.02	<0.03	<0.03	<0.03	40
SG-11-2'	0.001	0.02	0.008	14000	<0.5	<0.5	<0.7	<0.7	530
SG-21-1'	0.0006	<0.0002	0.0004	10	<0.02	<0.03	<0.03	<0.03	0.1
SG-22-1'	0.0005	0.001	<0.00003	80	0.9	0.8	<0.03	<0.03	3
SG-31-1'	0.0004	<0.0002	0.00005	2	<0.02	<0.03	<0.03	<0.03	<0.03
SG-30-1'	0.0004	<0.0002	0.00004	2	<0.02	<0.03	<0.03	<0.03	<0.03
SG-28-1'	0.0004	<0.0002	<0.00003	2	<0.02	<0.03	<0.03	<0.03	<0.03

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Table 5-4

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Sample	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	TPH (µg/L)
03/25/90									
AIR	0.0006	<0.0002	0.00009	2	<0.03	<0.03	<0.03	<0.03	<0.03
SG-19-2'	0.0004	<0.0002	0.00009	2	<0.03	<0.03	<0.03	<0.03	<0.03
SG-10-2'	0.0006	0.0007	0.0002	680	<0.03	<0.03	<0.03	<0.03	<0.03
SG-1-2'	0.0005	<0.0002	0.00007	40	<0.03	<0.03	<0.03	<0.03	<0.03
SG-64-3'	0.0004	0.002	0.00009	580	<0.03	<0.03	<0.03	<0.03	<0.03
SG-65-2'	0.0004	<0.0002	0.0002	110	<0.03	<0.03	<0.03	<0.03	<0.03
03/27/90									
AIR	0.0005	<0.0002	0.0001	2	<0.02	<0.03	<0.04	<0.04	<0.03
SG-3-2'	0.0001	0.002	0.0006	6000	<0.02	<0.03	<0.04	<0.04	4
SG-2-2'	0.0002	0.003	0.02	240	<0.02	<0.03	<0.04	<0.04	<0.03
SG-13-1'	0.001	<0.0002	0.0002	60	0.05	<0.03	<0.04	<0.04	0.06
03/28/90									
AIR	0.002	<0.0002	0.0004	2	<0.02	<0.03	<0.03	<0.03	<0.03
SG-71-2'	0.0005	<0.0002	0.0002	10	<0.02	<0.03	<0.03	<0.03	<0.03
SG-75-1'	0.0006	0.005	0.0005	20	<0.02	<0.03	<0.03	<0.03	<0.03
SG-76-2'	0.0005	<0.0002	0.0002	20	<0.02	<0.03	<0.03	<0.03	<0.03
SG-77-1'	0.0006	<0.0002	0.0002	3	<0.02	<0.03	<0.03	<0.03	<0.03
SG-78-1'	0.0005	0.002	0.0003	830	<0.02	<0.03	<0.03	<0.03	<0.03

KN/1256/SWMU6/SWMU6.5-4/04-07-94/D1

Table 5-4

(Page 4 of 4)

Sample	TCA (µg/L)	TCE (µg/L)	PCE (µg/L)	Methane (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl Benzene (µg/L)	Xylenes (µg/L)	TPH (µg/L)
03/28/90 (Continued)									
SG-79-1'	0.004	0.008	0.001	8000	60	<0.03	5	<0.03	100
AIR	0.001	<0.0002	0.0001	5	<0.02	<0.03	<0.03	<0.03	<0.03
03/29/90									
AIR	0.0005	<0.0003	0.0001	2	<0.02	60.03	<0.03	<0.04	<0.03
SG-80-1'	0.0004	0.001	0.0001	2	0.04	<0.03	<0.03	<0.04	0.04
SG-81-2'	0.0005	<0.0003	0.00008	2	<0.02	<0.03	<0.03	<0.04	<0.03
SG-82-1'	0.0004	0.0007	0.02	650	<0.02	<0.03	<0.03	<0.04	<0.03
SG-83-1'	0.0003	0.008	0.01	4000	<0.02	<0.03	2	<0.04	2
SG-89-2'	0.0004	<0.0003	0.0002	1	<0.02	<0.03	<0.03	<0.04	<0.03
SG-90-2'	0.0008	<0.0003	0.0008	2	<0.02	<0.03	<0.03	<0.04	<0.03
SG-91-2'	0.0006	0.0004	0.0001	1	<0.02	<0.03	<0.03	<0.04	<0.03
AIR	0.007	<0.0003	0.00008	1	<0.02	<0.03	<0.03	<0.04	<0.03

[a]Data from shallow soil gas investigation, Landfills No. 2 and 4, Tinker AFB, Oklahoma (Tracer, 1990)

Table 5-5

Summary of Analytical Results for Surface Leachate and Drainage Samples SWMU-6, Landfill 4, Tinker AFB

(Page 1 of 2)

Sample Type Sample No. Sample Date	Leachate[a] NA 1979	Drainage Creek[a] NA 1979	Leachate[b] NA 1984	Leachate[c] L4-7 1987	Leachate[c] L4-8 1987
Volatiles (μg/L)					
Acetone	NA	NA	NA	110	<200
Chlorobenzene	NA	NA	NA	<50	69J
Semivolatiles (μg/L)					
Bis(2-ethylhexyl)phthalate	NA	NA	NA	NT	6J
1,4-Dichlorobenzene	NA	NA	NA	NT	14J
Diethyl phthalate	NA	NA	NA	NT	13J
2,4-Dimethylphenol	NA	NA	NA	NT	34J
Phenol	NA	NA	NA	NT	14J
Metals (μg/L)					
Barium	8000	24000	NT	NT	NT
Iron	24000	21000	5000	NT	NT
Manganese	9600	9800	330	NT	NT
Mercury	5300	7200	<0.5	NT	NT
Nickel	1100	650	730	NT	NT
Zinc	11000	980	<3	NT	NT

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Table 5-5

(Page 2 of 2)

Sample Type Sample No. Sample Date	Leachate[a] NA 1979	Drainage Creek[a] NA 1979	Leachate[b] NA 1984	Leachate[c] L4-7 1987	Leachate[c] L4-8 1987
Indicators (mg/L)					
COD	29000	910	NT	NT	NT
Oil and grease	400	76	<0.10	NT	NT
Phenols	9.6	1.2	0.21	NT	NT
TOC	NT	NT	340	NT	NT
TOX	NT	NT	1.5	NT	NT

[a]Data from Installation Restoration Program, Phase I - Records Search, Tinker AFB, Oklahoma (ES, 1982).
[b]Data from Installation Restoration Program, Phase II - Confirmation I Quantification, Stage I, Tinker AFB, Oklahoma (Radian, 1985a).
[c]Data from Landfills 1-4 RI Report, Tinker AFB, Oklahoma (USACE, 1993).
NA = Data not available.

Table 5-6

Groundwater Contaminant Summary
1987 Trench Water Sampling
(USACE, 1993)
SWMU-6, Landfill 4, Tinker AFB

(Page 1 of 3)

Boring Number	L4-1	L4-2	L4-2	L4-4	L4-5	L4-5	L4-6
Sample Number	7-190	7-208	NA	7-175	7-181	NA	7-209
Sample Date	2/87	2/87	9/89	2/87	2/87	9/89	2/87
Volatiles (µg/L)							
Acetone	25	28000	110	5100	14000	55	160
2-Butanone	<10	41000	160	1700	17000	120	730
Chlorobenzene	3 J	89	170	<500	<500	4 J	25 J
Trans-1,2-dichlorothene	6	<25	<5	<500	500 J	<5	<25
Ethyl benzene	6	71	NA	<500	<500	NA	52
2-Hexanone	15	7000	<10	540 J	2600	<10	<50
4-Methyl-2-pentanone	<10	84	NA	<1000	<1000	NA	<50
Methylene chloride	<5	74	<5	470 J	640	2B J	8 J
Toluene	<5	280	41	540	1100	6	<25
Vinyl acetate	<10	1600	NA	<1000	<10000	NA	<50
Xylenes	<5	94	NA	<500	<500	NA	160
Semivolatiles (µg/L)							
Benzoic acid	<50	<25000	NA	960	<1000	NA	<25000
Bis(2-ethylhexyl)phthalate	20	<5000	<100	<100	<200	<100	<5000
1,4-Dichlorobenzene	15	<5000	61 J	<100	42 J	<100	<5000
Diethyl phthalate	<10	4700 J	190	<100	750	110	<5000
2,4-Dimethylphenol	19	<5000	<100	<100	110 J	100	<5000

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Table 5-6

(Page 2 of 3)

Boring Number	L4-1	L4-2	L4-2	L4-4	L4-5	L4-5	L4-6
Sample Number	7-190	7-208	NA	7-175	7-181	NA	7-209
Sample Date	2/87	2/87	9/89	2/87	2/87	9/89	2/87
Semivolatiles (µg/L) (Continued)							
4-Methylphenol	<10	11000	270	1300	2200	420	<5000
n-Nitrosodiphenylamine	11	<5000	NA	<100	<200	NA	<5000
Phenol	<10	19000	290	<100	2300	190	<5000
Metals (µg/L)							
Arsenic	6.3	30	1.1	4.6	6	5.6	14
Barium	740	5000	9500	3400	4300	14000	5000
Cadmium	<7.5	4400	16	23	33	30	60
Chromium	20	490	88	78	140	50	30
Iron	3300	1300000	16000	180000	1000000	65	25000
Lead	40	2600	44	110	200	58	170
Manganese	210	37000	280	3300	34000	16	750
Mercury	0.15	18	<0.1	1.2	0.25	<0.1	8.1
Nickel	48	6600	NT	980	1600	NT	490
Silver	<10	40	<5	13	30	<5	<10
Zinc	210	95000	NT	4000	53000	NT	2500
Radiometric Parameters (pCi/L)							
Gross alpha	<2	232±79	49±113	37±23	<2	0±48	37±28
Gross beta	11±5	421±43	66±78	31±11	59±7	55±48	72±16
Total radium	<1	<1	437±90	29±8	29±9	1±1	16±7

Table 5-6

(Page 3 of 3)

Boring Number	L4-1	L4-2	L4-2	L4-4	L4-5	L4-5	L4-6
Sample Number	7-190	7-208	NA	7-175	7-181	NA	7-209
Sample Date	2/87	2/87	9/89	2/87	2/87	9/89	2/87
Indicators (mg/L)							
TOC	44	9400	25.6	960	6200	14.1	630
Oil and grease	<1	1800	<1	69	1100	<0.2	2.4
Chloride	240	1100	1250	190	680	780	670
Sulfate	170	720	7.6	197	1000	18	124
pH (s.u.)	7.11	5.99	7.22	6.30	5.94	6.93	6.32
Conductivity (μmhos/cm)	2710	15760	5450	3.48	7640	4410	5110

NT = Compound not tested for.
B = Compound also present in blank.
J = Compound present below laboratory detection limits.
NA = Data not available.

During the 1990 LIF-CPT study, ARA collected five groundwater samples from the USZ for VOC analysis. Two of the samples were analyzed on site, and the remaining three samples were submitted for off-site analysis. Table 5-7 presents a summary of the analytical results for these samples.

Monitoring wells installed in the vicinity of the landfill in the USZ and the LSZ were sampled to determine the magnitude and extent of contaminant migration. Groundwater samples were collected from nearby wells by the USACE from 1986 to 1990 during the RI, and selected monitoring wells have been sampled as a part of the Base groundwater monitoring program. Monitoring wells 10A, 10B, 11C, and 46B in the vicinity of Landfill 4 are screened in the USZ, while monitoring well 10C is screened in the LSZ. Well 46A is located in the vicinity of Landfill 4; however, it is screened across both the USZ and the LSZ and, therefore, will not be used to characterize either zone. A summary of the 1986 to 1992 groundwater results are presented in Table 5-8 for the USZ and in Table 5-9 for the LSZ.

5.1 Constituents of Potential Concern

The results of soil, soil gas, surface water, and groundwater analyses of samples collected from Landfill 4 are available from past IRP investigation activities. Evaluation of these analytical results for the purpose of identifying constituents of potential concern with respect to both human health and the ecological impacts has not been performed. However, an interpretation has been made comparing the analytical results to USGS background concentrations in soils and groundwater. The following sections summarize these interpretations.

5.2 Soil Characterization

During the RI, the USACE assessed the magnitude and extent of contamination originating from historical landfill disposal practices. In 1987, six soil borings (L4-1 through L4-6) were advanced into the former trench areas within the landfill. One sample was collected from each boring. In addition, surface soils were sampled at two locations within the landfill. The soil samples were analyzed for VOCs, SVOCs, metals, and indicator parameters. The results of the 1987 surface and subsurface soil investigations are presented in Table 5-2.

Fourteen VOCs and nine SVOCs were detected in the trench boring samples. The highest concentrations of organic contaminants were found in boring L4-5. The highest organic concentration detected was for 2-butanone at 200,000 microgram per kilogram (μg/kg). Other organic compounds with elevated concentrations included acetone (23,000 μg/kg), 2-hexanone (5,600 μg/kg), 4-methyl-2-pentanone (5,530 μg/kg), phenol (5,500 μg/kg), diethyl phthalate

Table 5-7

Summary of Analytical Results for Groundwater[a]
1992 Cone Penetrometer Study
SWMU-6, Landfill 4, Tinker AFB

CPT Push Site Sample Depth (ft) Sample Date	LF4-05WS 8 10/92	LF4-05 9 10/92	LF4-06 4 10/92	LF4-06WS 14.5 10/92	LF4-06 15.5 10/92
Volatiles (μg/L)					
Benzene	NT	110	<5	NT	<5
Bromoform	NT	37	<5	NT	<5
Chlorobenzene	NT	<5	50	NT	15
1,1-Dichloroethane	21	17	<5	6	<5
1,2-Dichloroethane	23	21	<5	<4	<5
Trans-1,2-dichloroethene	NT	220	<5	NT	<5
Ethyl benzene	NT	230	110	NT	160
Methylene chloride	248	<5	<5	<4	<5
Tetrachloroethene	NT	35	<5	NT	<5
Trichloroethene	102	200	<5	<4	<5
Toluene	NT	3400	<5	NT	<5
Xylenes	NT	570	170	NT	<5

[a]Data from Tables 26 and 28 of Laser Induced Fluorescence Cone Penetrometer Investigation Report (ARA, 1993).

Table 5-8

Summary of 1986-1992 Analytical Results
Upper Saturated Zone Monitoring Wells
SWMU-6, Landfill No. 4, Tinker AFB

(Page 1 of 6)

Well Number	10B[a]			10A[a]					11C		
Sample Number	8-1468	9-1229	0-2111	6-372[b]	8-1467	9-1707	0-2164	9-21111	8-1449	9-1239	0.2126
Sample Date	09-27-88	08-31-89	06-27-90	05-22-86	09-27-88	09-27-89	07-05-90	11-11-92	09-25-88	09-05-89	06-28-90
Volatiles (µg/L)											
Acetone	<10	25	<10	NA	NA	NA	NA	NA	<10	<10	<10
Benzene	NA	<5	<5	NA	NA	NA	NA	NA	<5	<5	<5
Chlorobenzene	<5	<5	<5	< 5	< 5	< 5	< 5	0.3J	<5	<5	<5
Cis-1,2-dichloroethene	NA	NT	NT	NA	NA	NA	NA	NA	NT	NT	NT
Trans-1,2-dichloroethene	<5	<5	<5	NA	NA	NA	NA	NA	<5	<5	<5
Ethyl benzene	NA	<5	<5	NA	NA	NA	NA	NA	<5	<5	<5
Methylene chloride	<5	<5	<5	<5	<5	<5	<10	0.7B	<5	<5	<5
Tetrachloroethene	NA	<5	<5	NA	NA	NA	NA	NA	<5	<5	<5
Toluene	<5	<5	<5	NA	NA	NA	NA	NA	<5	<5	<5
1,1,1-Trichloroethane	NA	<5	<5	NA	NA	NA	NA	NA	<5	<5	<5
Trichloroethene	<5	<5	<5	<5	1J	<5	<5	3	2J	<5	<5
Semivolatiles (µg/L)											
Bis(2-ethylhexyl)phthalate	5J	<10	97B	<10	4J	5bJ	19B	<9	7J	<10	<10
1,2-Dichlorobenzene	NA	<10	<17	NA	NA	NA	NA	NA	<10	<10	<10
1,4-Dichlorobenzene	NA	NA	NA	<10	<10	10	10	0.3J	NA	NA	NA

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Table 5-8

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Well Number	10B[a]			10A[a]					11C		
Sample Number	8-1468	9-1229	0-2111	6-372[b]	8-1467	9-1707	0-2164	9-21111	8-1449	9-1239	0.2126
Sample Date	09-27-88	08-31-89	06-27-90	05-22-86	09-27-88	09-27-89	07-05-90	11-11-92	09-25-88	09-05-89	06-28-90
Semivolatiles (µg/L) (Continued)											
Di-n-butyl pthalate	NA	<10	2BJ	NA	NA	NA	NA	NA	<10	<10	0.2BJ
Isopropylbenzene	NA	NT	NT	NA	NA	NA	NA	NA	NT	NT	NT
Naphthalene	NA	<10	<17	NA	NA	NA	NA	NA	<10	<10	<10
Dimethyl phthalate	NA	<10	<17	NA	NA	NA	NA	NA	<10	<10	<10
Di-n-octyl phthalate	<10	<10	<17	<10	<10	2BJ	<10	<9	2J	2J	<10
Metals (µg/L)											
Arsenic	7.1	2	2.3	1.4	2.1	2	2.3	<2	4	1.5	2.9
Barium	250	150	14.3	<500	310	220	32.7	204	160	87	11.5
Cadmium	<5	<5	<10	10	<5	<5	<10	<5	<5	<5	<10
Chromium	<5	7.8	11.2	110	560	660	110	1500	<5	<5	<10
Iron	NT	310	332	NT	NT	6	18.3	NT	NT	120	101
Lead	27	18	<20	43	11	14	<20	<42	18	<10	<20
Manganese	NT	70	17.8	NT	NT	52	6	NT	NT	130	<5
Mercury	<0.1	1	<0.2	NA	NA	NA	NA	NA	<0.1	<0.1	<0.2
Nickel	NT	NT	NT	28	NT	NT	NT	<15	NT	NT	NT
Selenium	1.7	2.6	7.6	0.7	1.4	<0.4	<1	<2	0.9	0.4	<1
Zinc	NT	NT	NT	55	NT	NT	NT	NT	NT	NT	NT
Radiometrics (pCi/L)											
Gross alpha	NT	0±42.3	7±5	12±5	NT	1.14±6.43	3±2	NT	NT	12.3±9.21	7±3
Gross beta	NT	63.6±33.6	8±3	10±3	NT	0±6.46	<3	NT	NT	10.1±6.76	5±3

KN/1256/SWMU6/SWMU6.5-8/10-05-94/D6 4:38pm

Table 5-8

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Well Number	10B[a]			10A[a]					11C		
Sample Number	8-1468	9-1229	0-2111	6-372[b]	8-1467	9-1707	0-2164	9-21111	8-1449	9-1239	0.2126
Sample Date	09-27-88	08-31-89	06-27-90	05-22-86	09-27-88	09-27-89	07-05-90	11-11-92	09-25-88	09-05-89	06-28-90
Radiometrics (pCi/L) (Continued)											
Total radium	NT	0.41±0.19	2±1	NT	NT	0.15±0.12	2±1	NT	NT	0.75±0.4	2±1
Radium-226	NT	NT	NT	NA	NA	NA	NA	NA	NT	NT	NT
Radium-228	NT	NT	NT	NA	NA	NA	NA	NA	NT	NT	NT
Indicators (mg/L)											
pH (s.u.)	8.49	8.22	7.53	7.26	7.37	7.46	7.18	NT	NT	7.4	7.57
Chloride	52	1040	2850	31	45	55	38.8	NT	66	65.9	59.4
Sulfate	150	190	480	11	230	15	16.5	NT	110	220	204
Oil and grease	NT	<1	12	<1	NT	<0.2	<5	NT	NT	<1	5.6
TDS	NT	NT	NT	NA	NA	NA	NA	NA	NT	NT	NT
TOC	<0.1	0.613	<0.5	4	0.18	0.89	0.667	NT	2.5	1.4	0.79
Conductivity (µmhos/cm)	3540	2790	4500	954	875	890	895	NT	NT	1020	1372

Table 5-8

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Well Number	46B[a]				
Sample Number	6-387	8-1327	9-1349	0-945	9-21209
Sample Date	05-29-86	09-11-88	09-14-89	03-21-90	12-09-92
Volatiles (µg/L)					
Acetone	<10	<10	<10	<10	NT
Benzene	<5	<10	<5	<5	<0.5
Chlorobenzene	<5	<5	<5	<5	<0.5
Cis-1,2-dichloroethene	NT	NT	NT	NT	<0.5
Trans-1,2-dichloroethene	<5	<5	<5	<5	<0.5
Ethyl benzene	<5	<5	<5	<5	<0.5
Methylene chloride	<5	<5	<5	14B	0.8B
Tetrachloroethene	<5	<5	<5	<5	<0.5
Toluene	<5	<5	<5	<5	<0.5
1,1,1-Trichloroethane	<5	<5	<5	<5	<0.5
Trichloroethene	<5	<5	7	<5	3
Semivolatiles (µg/L)					
Bis(2-ethylhexyl)phthalate	<10	<10	<10	<10	35
1,2-Dichlorobenzene	<10	<10	<10	<10	<0.5
1,4-Dichlorobenzene	NA	NA	NA	NA	NA

Table 5-8

(Page 5 of 6)

Well Number	46B[a]				
Sample Number	6-387	8-1327	9-1349	0-945	9-21209
Sample Date	05-29-86	09-11-88	09-14-89	03-21-90	12-09-92
Semivolatiles (μg/L) (Continued)					
Di-n-butyl pthalate	<10	<10	<10	0.3BJ	1J
Isopropylbenzene	NT	NT	NT	NT	<0.5
Naphthalene	<10	<10	<10	<10	0.8B
Dimethyl phthalate	<10	<10	<10	<10	<10
Di-n-octyl phthalate	<10	<10	<10	<10	<10
Metals (μg/L)					
Arsenic	3	1.7	2.6	3.3	<2
Barium	650	88	88	75	74
Cadmium	13	<5	<5	<10	<5
Chromium	85	<5	5.5	<10	<7
Iron	NT	NT	NT	NT	NT
Lead	60	<10	14	<20	<42
Manganese	NT	NT	NT	NT	NT
Mercury	<0.4	<0.1	<0.1	<0.2	<0.2
Nickel	100	12	16	<15	<15
Selenium	2.2	1.8	2.3	<1	5.6
Zinc	140	<5	<5	<10	NT
Radiometrics (pCi/L)					
Gross alpha	16±4	NT	NT	NT	NT
Gross beta	52±14	NT	NT	NT	NT

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Table 5-8

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Well Number	46B[a]				
Sample Number	6-387	8-1327	9-1349	0-945	9-21209
Sample Date	05-29-86	09-11-88	09-14-89	03-21-90	12-09-92
Radiometrics (pCi/L) (Continued)					
Total radium	NT	NT	NT	NT	NT
Radium-226	2±1.85	NT	NT	NT	NT
Radium-228	7±5	NT	NT	NT	NT
Indicators (mg/L)					
pH (s.u.)	7.16	7.46	7.62	7.54	NT
Chloride	53	47	52.1	120	NT
Sulfate	75	52	11.2	160	NT
Oil and grease	1	NT	NT	NT	NT
TDS	NT	NT	NT	NT	NT
TOC	5	0.73	0.817	<0.5	NT
Conductivity (µmhos/cm)	1153	526	590	1789	NT

[a]No 1986, 1987, 1991, and 1992 data available for monitoring wells 10B and 11C. No 1987 and 1991 data available for monitoring well 46B. No 1986 and 1991 data available for monitoring well 60C.
[b]Sample number 6-372 was collected from monitoring well 10, which was later renumbered as 10A.

NA = Data not available.
NT = Compound not tested for.
B = Compound also found in blank.
J = Compound present below laboratory detection limit.
E = Estimated - exceeded calibration limits.

Table 5-9

Summary of 1986-1992 Analytical Results
Lower Saturated Zone Monitoring Wells
SWMU-6, Landfill 4, Tinker AFB

(Page 1 of 2)

Well Number	10C			
Sample Number	9-1469	9-1230	0-2112	9-21111
Sample Date	09-27-88	08-31-89	06-27-90	11-11-92
Volatiles (µg/L)				
1,2-Dichloroethane	<5	<5	<5	2
Cis-1,2-dichloroethene	NT	NT	NT	1
Methylene chloride	<5	<5	<5	0.7B
Trichloroethene	<5	<5	<5	3
Semivolatiles (µg/L)				
Naphthalene	<10	<10	<20	4B
Dimethyl phthalate	<10	<10	<20	16
Metals (µg/L)				
Arsenic	9.7	3.7	3.8	<2
Barium	740	410	27.7	204
Chromium	7	9.5	<10	1500
Iron	NT	180	97.9	NT
Lead	12	<10	<20	<42
Manganese	NT	22	<5	NT
Mercury	<0.1	0.58	<0.2	<0.2
Selenium	0.7	<0.4	<1	<2
Radiometrics (pCi/L)				
Gross alpha	NT	0.19±4	3±2	NT
Gross beta	NT	9.27±4.58	<3	NT
Total radium	NT	0.33±0.2	2±1	NT
Indicators (mg/L)				
pH (s.u.)	8.09	7.83	8.42	NT
Chloride	28	8.28	3.94	NT
Sulfate	17	15	11.7	NT
Oil and grease	NT	<1	11	NT
TDS	NT	NT	NT	500

Table 5-9

(Page 2 of 2)

Well Number	10C			
Sample Number	9-1469	9-1230	0-2112	9-21111
Sample Date	09-27-88	08-31-89	06-27-90	11-11-92
Indicators (mg/L) (Continued)				
TOC	<0.1	0.517	<0.5	<1
Conductivity (µmhos/cm)	405	460	615	NT

NA = Data not available.
NT = Compound not tested for.
B = Compound also found in blank.
J = Compound present below laboratory detection limit.

(5,200 μg/kg), and bis(2-ethylhexyl)phthalate (5,100 μg/kg). In general, VOC contamination was widespread among the subsurface samples. Only five of the fourteen VOCs (benzene, carbon disulfide, styrene, tetrachloroethene, and trichloroethene) were detected in fewer than four out of six samples. SVOCs were detected more sporadically, with most of the detections originating from boring L4-5. Only bis(2-ethylhexyl)phthalate and diethyl phthalate were detected in more than one sample.

Four metals (chromium, lead, nickel, and zinc) were detected above USGS background concentrations. Metals contamination was widespread throughout the subsurface samples collected, with elevated levels of metals detected in five out of six borings.

Significantly lower levels of contamination were detected in the two surface soil samples. Only two VOCs and one SVOC were detected in these samples. The highest organic concentration detected was for diethyl phthalate at 180J μg/kg. Two metals, lead and zinc, were detected above USGS background concentrations, but none of the detected values were more than one order of magnitude above USGS background.

During the 1992 CPT study at the sludge dump area in Landfill 4, ten soil samples were collected and analyzed for VOCs, PAHs, and metals. Table 5-3 presents a compilation of the analytical results for these samples. Five VOCs and eight SVOCs were detected. Arsenic, chromium, lead, and zinc were detected above USGS background concentrations. Cadmium was detected at a concentration of 47 milligrams per kilogram (mg/kg), slightly above the 40 mg/kg corrective action limit for this analyte. All of the VOCs and SVOCs were detected at one CPT push site (LF4-06). VOC concentrations were low, relative to the results of the 1987 subsurface investigation. SVOC concentrations ranged from 930 to 8,300 μg/kg, with benzo(b)fluoranthene registering the highest concentration. The concentrations of metals were within the ranges detected during the 1987 subsurface investigation, with the exception of one lead value (1,400 mg/kg) at CPT push site LF4-05, which was almost one order of magnitude above the highest detection in the previous investigation.

5.3 Soil Gas Characterization

Forty-seven soil gas samples were collected in and around the landfill during the SGI in 1990. The samples were collected at depths of 1 to 6 feet below grade. The analytical results of the SGI are presented in Table 5-4. Maps depicting sampling locations, compound concentrations, and isoconcentration contours are presented in Figures 1-20 of the SGI report (Tracer, 1990). All the VOCs selected for analysis were detected during the survey, with the exception of xylenes.

The methane concentrations detected produced the most significant and contourable plumes across the landfill. Most of the landfill was contained within a 10 μg/L methane contour line with the highest concentration of methane (14,000 micrograms per liter [μg/L]) detected west of the sludge dump at sampling point 11.

One significant benzene plume was detected at sampling point 79, with a maximum concentration of 60 μg/L. This sampling point was also the location of the only ethyl benzene plume in the landfill, with a maximum concentration of 5 μg/L. One toluene plume with a maximum concentration of 30 μg/L was detected in the vicinity of the sludge dump.

Small plumes of trichloroethene, trichloroethane, and tetrachloroethene were also detected within the vicinity of the sludge dump. A large trichloroethane plume stretched from an area west of the sludge dump at sampling points 11 and 20, through the sludge dump, to an area north of the sludge dump at sampling point 4. The highest trichloroethane concentration in this plume (0.05 μg/L) was detected at sampling location L4-20 within the sludge dump. A large tetrachloroethene plume was located across the northern portion of the landfill at sampling points 2, 82, and 83. The highest concentration in this plume was 0.02 μg/L.

5.4 Surface Water Characterization

Surface leachate samples were collected at the landfill in 1979, 1984, and 1987. The results of these sampling efforts are presented in Table 5-5. The analytical results from the 1979 investigation indicated high concentrations of COD, oil and grease, phenols, and heavy metals. The concentrations of metals and indicator parameters detected during the 1984 sampling round were significantly less than the 1979 results. The 1987 results show that two VOCs and five SVOCs were detected in leachate samples.

5.5 Groundwater Characterization

The quality of the groundwater in and around the landfill is discussed in the following sections. Trench water in the area of the landfill trenches and sludge dump was sampled in 1987 and 1989 during the RI. Groundwater contamination in the two aquifers under the site was further characterized by sampling monitoring wells in the vicinity of the landfill from 1986 to 1990 during the RI. Selected monitoring wells have been sampled since 1990 as part of the facility groundwater monitoring program.

5.5.1 Landfill Trench Water

The landfill trenches and sludge dump sites at Landfill 4 were constructed within the USZ aquifer. Table 5-6 presents a summary of the analytical data collected during groundwater investigations at the landfill in 1987 and 1989. The data represents the quality of USZ groundwater in the vicinity of the landfill trenches and the sludge dump.

Eleven VOCs and seven SVOCs were detected in trench water samples collected at the landfill. Three organic compounds (chlorobenzene, acetone, and toluene) were detected above either the maximum containment level (MCL) or CALs. Three of the organic compounds were detected at concentrations greater than 1,000 µg/L. The highest organic concentration detected was 2-butanone at 41,000 µg/L. The most elevated organic concentrations were found in borings L4-2 and L4-5.

The following seven metals were detected above MCLs barium, cadmium, chromium, lead, manganese, nickel, and zinc. Iron has no MCL but was detected at the highest concentration (1,300,000 µg/L). Cadmium, lead and manganese were detected at concentrations more than two orders of magnitude above their MCLs. The most elevated metals concentrations were detected in borings L4-2 and L4-5. The maximum concentration for eight metals were found in boring L4-2.

Elevated levels of radiometric parameters were detected in 4 of the 6 borings at the landfill. The maximum concentration of all three radiometric parameters detected at Landfills 1 through 4 was found in boring L4-2. Gross alpha was detected at 232 plus or minus 79 picocuries per liter (pCi/L), gross beta at 21 plus or minus 43 pCi/L, and total radium at 437 plus or minus pCi/L.

Table 5-7 shows the analytical results for five groundwater samples that were collected from the USZ in the vicinity of the sludge dump during the 1992 CPT study at Landfill 4. A VOC scan of the samples detected the presence of 12 VOCs. Eight of the 12 VOCs detected were above MCLs. The VOC with the highest concentration was toluene at 3,400 µg/L.

5.5.2 USZ Groundwater

A summary of the 1986-1992 groundwater results for USZ monitoring wells is presented in Table 5-8. Eleven VOCs and eight SVOCs were detected sporadically in wells 10A, 10B, 11C, and 46B. The following three organic compounds were detected above MCLs: bis(2-ethylhexyl)phthalate, methylene chloride, and trichloroethene. Only 9 organic compounds were detected in the USZ monitoring wells. All organic concentrations were below 100 µg/L. µ

Eleven metals were detected in USZ groundwater in the vicinity of Landfill 4. Four metals were detected at concentrations above MCLs: cadmium, chromium, lead, and manganese. Cadmium was detected above its MCL in 3 of 21 samples with a maximum detection of 13 µg/L at monitoring well 46B. Chromium was detected in five of six wells with a maximum concentration of 1,500 µg/L. Lead was detected above its action level in five of six wells with a maximum concentration of 60 µg/L at monitoring well 46B. Manganese was detected above its MCL in four of seven samples with a maximum concentration of 130 µg/L at monitoring well 11C.

The radiometric parameters gross alpha, gross beta, and total radium were detected in several samples. The highest gross alpha concentration of 16 pCi/L was detected in monitoring well 46B. The maximum gross beta concentration at 63.6 was detected in monitoring well 10B. The maximum total radium concentration was detected in monitoring well 11C at 2 pCi/L.

5.5.3 LSZ Groundwater

A summary of the 1986-1992 groundwater results for the LSZ monitoring well in the vicinity of Landfill 4 is presented in Table 5-9. Four VOCs and two SVOCs were detected sporadically in monitoring well 10C. No organics were detected above MCLs. The organic compound with the highest concentration was dimethyl phthalate at 16 µg/L.

Eight metals were detected in monitoring well 10C. Chromium was the inorganic constituent detected above the MCL, with the maximum detected value of 1,500 µg/L.

All three radiological parameters were detected in LSZ monitoring wells. The maximum concentration of gross alpha was 3 plus or minus 2 pCi/L. The maximum concentration of gross beta was 9.27 plus or minus 4.58 pCi/L, detected in August 1989. The maximum concentration of total radium was 2 plus or minus 1 pCi/L, detected in June 1990.

6.0 Potential Receptors

A preliminary draft baseline risk assessment report (USACE, 1991) for Landfills 1 through 4 was issued by USACE in February 1991. The purpose of the risk assessment was to quantify the potential health risks to human receptors at the four sites. The risk assessment was prepared in accordance with EPA guidance documents current at the time. An assessment of site risks to ecological receptors was not included in the report.

The risk assessment treated Landfills 1 through 4 as one site. Therefore, the risks associated with Landfill 4 alone cannot be abstracted from the report. The following is a discussion of the potential receptors identified by the preliminary draft baseline risk assessment report.

6.1 Exposure Assessment Results/Human Receptors

An exposure assessment was performed to determine the potential human receptors and analyzed the potential exposure pathways at Landfills 1 through 4. Potentially exposed human populations were limited to industrial workers associated with Base operations for the following reasons:

- No completed exposure pathway exists now or in the foreseeable future which would potentially expose individuals outside the boundaries of Tinker AFB.
- Access to Tinker AFB is restricted to military personnel, civilian employees, and individuals such as retirees who are authorized to use Base facilities.
- Military housing on Tinker AFB is limited and is not in the vicinity of the Landfills 1 through 4 sites.

There were no sensitive subpopulations identified within the industrial site workers determined to represent the potentially exposed population at the sites.

The land use at and near the Base is not expected to change because the facilities have decades of useful life remaining and the Base has an important and continuing mission. Conversion of nearby land to residential use is improbable because of noise and safety concerns associated with such land use around an active airport.

Potential groundwater contamination via migration of landfill leachate was not identified as a significant transport mechanism. It was determined that contamination of useable groundwater was not possible because of the great horizontal and vertical distances to groundwater use points, and the natural geophysical impediments to contaminant movement in the area. All homes in the area around and downgradient of Landfills 1 through 4 are served by municipal water. Therefore, the potential exposure route involving ingestion of contaminated groundwater was determined to be incomplete for current and future scenarios.

The only complete exposure pathways identified during the exposure assessment are inhalation of contaminated soil particles and inhalation of organic vapors from contaminated soil.

A summary of the exposure pathways evaluated for potential receptors under current and future land use scenarios, and the rationale for inclusion or exclusion in the risk characterization is presented in Table 6-1.

6.2 Ecological Receptors

Tinker AFB lies within a grassland ecosystem, which is typically composed of grasses, forbes, and riparian (i.e., trees, shrubs, and vines associated with water courses) vegetation. This ecosystem has generally experienced fragmentation and disturbances as result of urbanization and industrialization at and near the Base. While no threatened or endangered plant species occur on the Base, the Oklahoma penstemon (*Penstemon oklahomensis*), identified as a rare plant under the Oklahoma Natural Heritage Inventory Program, thrives in several locations on Base. Tinker AFB policy considers rare species as if they were threatened or endangered and provides the same level of protection for these species.

In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base. However, one specie found on the Base, the Texas horned lizard (*Phrynosoma cornutum*), is a Federal Category 2 candidate specie and under review for consideration to be listed as threatened or endangered. Air Force policy (AFR 126-1) considers candidate species as threatened or endangered and provides the same level of protection.

The Oklahoma Department of Wildlife Conservation also lists several species within the state as Species of Special Concern. Information on these species suggests declining populations but information is inadequate to support listing, and additional monitoring of populations is needed to determine the species status. These species also receive protection by Tinker AFB as threatened or endangered species. Of these species, the Swainson's hawk (*Buteo*

Table 6-1

Summary of Complete Exposure Pathways
SWMUs 3-6, Landfills 1-4, Tinker AFB

Potentially Exposed Population	Exposure Route, Medium and Exposure Point	Pathways Selected for Evaluation?	Reason for Selection or Exclusion
Current Land Use			
Residents	Ingestion of groundwater from local wells downgradient.	No	Pathway is incomplete. All water is from municipal systems in areas downgradient from site.
Residents	Inhalation of contaminated particulates.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Inhalation of organic vapors.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Dermal contact with contaminated particulates.	No	General public does not have access to facility or site. Pathway is incomplete.
Residents	Incidental ingestion of contaminated particles.	No	General public does not have access to facility or site. Pathway is incomplete.
Industrial workers	Inhalation of contaminated particles.	Yes	Workers will be present intermittently in adjacent facilities.
Industrial workers	Inhalation of organic vapors.	Yes	Workers will be present intermittently in adjacent facilities.
Industrial workers	Dermal contact with contaminated particles.	No	Workers will not be present on the site. Pathway is incomplete.
Industrial workers	Incidental ingestion of contaminated particles.	No	Workers will not be present on the site. Pathway is incomplete.
Future Land Use			
It is anticipated that there will be no long-term change in land use because the site is located on a defense installation that has a critical, continuing mission			

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swainsoni) and the burrowing owl (*Athene cunicularia*) have been sighted on Tinker AFB. The Swainson hawk, a summer visitor and prairie/meadow inhabitant has been encountered Basewide. The burrowing owl has been known to inhabit the Air Field at the Base.

7.0 Action Levels

An "action level" is defined by EPA in proposed rule 40 CFR 264.521 (55 FR 30798; 7/27/90), "Corrective Action for Solid Waste Management Units (SWMU) at Hazardous Waste Management Facilities," as a health- and environment-based level, determined by EPA to be an indicator for protection of human health and the environment. In the preamble to this proposed rule, the focus of the RFI phase is defined as "characterizing the actual environmental problems at the facilities." As part of this characterization, a comparison of the contaminant concentrations to certain action levels should be made to determine if a significant release of hazardous constituents has occurred. This comparison is then used to determine if further action or corrective measures are required for a SWMU or an AOC. The preamble to the proposed rule states that the concept of action levels was introduced because of the need for "a trigger that will indicate the need for a Corrective Measures Study (CMS) and below which a CMS would not ordinarily be required" (55 FR 30798; 7/27/90). If constituent concentrations exceed certain action levels at a SWMU or an AOC, further action or a CMS may be warranted; if constituent concentrations are below action levels, a finding of no further action may be warranted. This chapter of the report presents the initial analytical data as compared to certain potential action levels.

Action levels are concentrations of contaminants at or below which exposure to humans or the environment should not produce acute or chronic effects.

The action level information is presented in this chapter so that a constituent concentration at a sample location can be compared with its potential action level. Only constituents identified in the analysis are listed in the SWMU-6, Landfill 4 table. Table 7-1 shows the action levels for soil, water, and air as published in federal or state regulations, policies, guidance documents, or proposed rules.

The action levels listed in Table 7-1 are:

- ***SWMU Corrective Action Levels (CAL)*** - The first set of action levels provided in the table are those taken from the proposed rule (40 CFR 264.521) and provided as Appendix A to the rule as "Examples of Concentrations Meeting Criteria for Action Levels." These levels are health-risk based and are provided

Table 7-1

Action Levels
SWMU 6, Landfill 4, Tinker AFB

(Page 1 of 2)

Parameters	SWMU CAL[a]			MCL[b]	USGS[c] Background	Site Background[d]		NAAQS[e]	WQS[f]
	Soil (mg/kg)	Water (mg/L)	Air ($\mu g/m^3$)	Water (mg/L)	Soil (mg/kg)	Water (mg/L) USZ	LSZ	Air (ug/m^3)	Water (mg/L)
Volatile Organics									
1,1-Dichloroethene	10		0.03	0.007					
1,2-Dichloroethane	8.0		0.04	0.005					
1,1,2-Trichloroethane	100	0.006	0.6	0.005					
Acetone	8000	4.0			0.0143	0.011	<0.010		
Benzene				0.005					0.714
Chlorobenzene	2000	0.7	20	0.1					
Chloroform	100	0.006	0.04	0.1					4.708
Cis-1,2-dichloroethene	8		0.04	0.07					
Ethyl benzene	8000	4.0		0.7		0.0051	<0.005		28.72
Methylene Chloride	90	0.005	0.3	0.005	0.014	0.0103	0.0038		
Styrene	20,000	7.0		0.1					
Tetrachloroethene	10	0.0007	1.0	0.005					
Toluene	20,000	10	7000	1.0					301.9
Trans-1,2-dichloroethene	8		0.04	0.1					
Trichloroethene	60			0.005		0.0073	<0.005		
Trichlorofluoromethane	20,000	10	700						
Vinyl Chloride				0.002					
Xylenes (total)	2.0×10^5	70	1000	10		0.0099	<0.005		
Semivolatile Organics									
1,2-Dichlorobenzene				0.6					
1,4-Dichlorobenzene				0.075					
Bis(2-ethylhexyl)phthalate	50	0.003		0.006		0.0096	0.010		
Butylbenzyl phthalate	20,000	7.0		0.1					
Chrysene				0.0002					
Diethyl phthalate	60,000	30							
Di-n-butyl phthalate	8000	4.0							

Table 7-1

(Page 2 of 2)

Parameters	SWMU CAL[a]			MCL[b]	USGS[c] Background	Site Background[d]		NAAQS[e]	WQS[f]
	Soil (mg/kg)	Water (mg/L)	Air (µg/m³)	Water (mg/L)	Soil (mg/kg)	Water (mg/L) USZ	Water (mg/L) LSZ	Air (ug/m³)	Water (mg/L)
Metals									
Arsenic	80		7.0×10^{-5}	0.05	21	0.001	0.0017		0.0014
Barium	4000		0.4	2	6400	2.235	0.766		
Cadmium	40		0.0006	0.005		0.0055	0.005		0.0841
Chromium VI	400		9.0×10^{-5}						
Chromium				0.1	110	0.0214	0.0120		3.365
Cyanide	2000	0.7		0.2					
Lead				0.015[g]	27	0.0129	0.0104	1.5[h]	0.025
Mercury	20			0.002		0.00014	0.00010		0.0006
Nickel	2000	0.7		0.1	61	0.053	0.047		4.583
Selenium				0.05	1.2	0.00086	0.00042		
Silver	200					0.005	0.005		64.62
Zinc					79	0.0088	0.0052		
Radiometrics									
Gross Alpha				15 pCi/L					
Radium-226+Radium-228				20 pCi/L					

[a]CAL - Corrective Action Levels
[b]MCL - Maximum Contaminant Levels
[c]USGS - United States Geological Survey
[d]Site background - Where available, site background concentrations are listed
[e]NAAQS - National Ambient Air Quality Standards
[f]WQS - Water Quality Standards
[g]Action Level at the Tap
[h]3 Month Average

as specific examples of levels below which corrective action would not be required.

- ***Maximum Contaminant Levels (MCL)*** - These values are provided from 40 CFR Subpart G, Sections 141.60 through 0.63 as promulgated under the Safe Drinking Water Act. These levels are designated for water media only.

- ***USGS Background*** - These values are provided from the USGS report titled "Elemental Composition of Surficial Materials from Central Oklahoma" (USGS, 1991). These values represent the levels of metals which naturally occur in Central Oklahoma soils.

- ***Background*** - These levels are provided where background could be determined. Where available, background concentrations are listed for metals in soil samples taken on site, which were thought to be unaffected by releases from a unit.

- ***National Ambient Air Quality Standards (NAAQS)*** - These standards are published in 40 CFR Part 50 under the Clean Air Act and apply to point sources that emit a limited number of constituents to the air. The constituents regulated are nitrogen dioxide, sulphur dioxide, carbon monoxide, lead, ozone, and particulate matter. Currently, it is assumed that none of the SWMUs or AOCs emit these compounds in regulated quantities and no air samples have been taken which would allow for a valid comparison.

- ***Water Quality Standards (WQS)*** - The WQS are the standards for surface water quality as established by the State of Oklahoma. These standards apply to point source discharges to surface waters and have been listed for those units adjacent to surface water.

8.0

8.0 Summary and Conclusions

Landfill 4 occupies approximately 12.4 acres and is located in the southwest corner of Tinker AFB. The landfill is south of Landfill Road and east of Patrol Road. Approximately 320,000 yd^3 of waste materials are estimated to have been deposited in the landfill between 1962 to 1968. The landfill was used primarily for the disposal of general refuse generated on base, but drums of materials including solidified solvents and metal shavings were also deposited in the landfill. The waste was placed in trenches running east-west across the site and covered daily with several inches of excavated native soil. One specific-use sludge dump was located in the central portion of the landfill. This area was used for landfarming sludges taken from the bottom of petroleum and solvent storage tanks.

8.1 Soils

The USACE conducted a RI of Landfills 1 through 4 from 1986 to 1990. During the soil investigations at Landfill 4, six borings were advanced into the soil at the former trench sites and sludge dump. Six subsurface and two surface soil samples were collected for analysis. In 1992, ARA collected ten soil samples from three borings advanced at CPT push sites in the vicinity of the sludge dump.

Analytical results from the soils investigations revealed that elevated levels of VOCs, SVOCs, and metals were detected in Landfill 4 soil samples. The highest concentrations of contaminants were detected around borings L4-2 and L4-3 in the vicinity of the sludge dump, and also at boring L4-5 west of the sludge dump. Elevated levels of metals above USGS background concentrations were consistently detected in subsurface samples.

Some organic contamination was also detected in surface soil samples, but concentrations were significantly below those detected in subsurface samples. Elevated levels of some metals were also detected in surface soil samples.

8.2 Soil Gas

In 1990, Tracer conducted a shallow SGI at Landfill 4. Samples were collected along grid points on 200-foot centers with the exception of a subsite survey at the sludge dump that was sampled on 50-foot intervals. Forty-seven soil gas samples were collected in and around the landfill, including eighteen samples in the area of the sludge dump. The samples were collected at depths of 1 to 6 feet below grade.

Soil gas samples were analyzed for methane, fuel components benzene, toluene, ethyl benzene, xylene (BTEX), three chlorinated VOCs, and total petroleum hydrocarbon. Concentrations of all the analytes were detected in soil gas with the exception of xylene. A significant methane plume was detected across most of the landfill with the highest concentrations in the general area of soil boring L4-5. Of the fuel components, the benzene plume was the largest and registered the highest concentrations. Smaller plumes of ethyl benzene and toluene were detected. One significant trichloroethane plume was detected, centered in the sludge dump and stretching to the north and the west. Smaller plumes of trichloroethene and tetrachoroethene were detected. A significant TPH plume was found with maximum concentrations located in the sludge dump and the boring L4-5 area.

8.3 Surface Water

There were locations along the northern and western slopes of the landfill where groundwater was at or near ground surface. These were the locations of leachate surface flows during and after periods of precipitation. Surface leachate samples were collected at the landfill in 1979, 1984, and 1987. The analytical results from the 1979 investigation indicated high concentrations of COD, oil and grease, phenols, and heavy metals. Barium, manganese, mercury, nickel, and zinc were all detected at elevated concentrations, with mercury over three orders of magnitude above its MCL. In general, contaminant concentrations detected during the 1984 sampling round are significantly less than the 1979 results. The 1987 results show that 2 VOCs and 5 SVOCs were detected in leachate samples.

8.4 Groundwater

Three groundwater zones were found in the vicinity of Landfill 4. The uppermost zone is called the HWBZ. This perched zone is underlain by a low permeability shale layer and hydraulically connected to the Landfill 4 landfill trenches and sludge dump. The HWBZ exists only in the vicinity of Landfills 2 and 4, and is not continuous across Tinker AFB, truncating to the north along Landfill Road. Although there appears to be very little vertical migration from the HWBZ to the underlying groundwater zones, the mounds occurring in the underlying USZ along Landfill Road indicate that the HWBZ may be hydraulically connected to the USZ. Because the USZ and the HWBZ are potentially connected they have been considered one zone in the groundwater quality discussions of this report. The RI report indicates that the HWBZ parallels the surface, and is only slightly below the surface over much of the landfill. There were locations along the northern and western slopes of the landfill where the water surface was at or near ground surface. These were the locations of leachate surface flows during and after periods of precipitation. Groundwater recharge in the HWBZ is primarily from surface infiltration.

The USZ is a sandstone unit unconfined across most of the Base. The USZ is underlain by a substantial layer of shale and siltstone from 8 to 25 feet thick across the Landfills 1 through 4 area. Vertical migration of the USZ groundwater contaminants occurs primarily by movement through preferential pathways in the formation under semi-confined and confined conditions, with the interbedded coarser grained material acting as a conduit to the LSZ below.

The LSZ is comprised primarily of interbedded shale, siltstone, and sandstone. The LSZ exists at depths of 50 to 70 feet below grade in the area of Landfills 1 through 4 and extends to a maximum depth of 125 feet before encountering a lower confining unit.

The quality of groundwater in the vicinity of Landfill No. 4 was evaluated during the RI from 1986 to 1990 by sampling trench water from borings in the landfill, and groundwater from monitoring wells installed in the USZ and LSZ adjacent to the landfill. Since 1990, selected wells have been sampled as part of the groundwater monitoring program.

The water samples collected from the soil borings are representative of the quality of groundwater in contact with landfill wastes. Analytical results from the trench water sampling indicate that elevated levels of VOCs, SVOCs, metals, and radiological parameters were detected. Eleven VOCs and seven SVOCs were detected in trench water samples. Three organic compounds were detected above MCLs. The highest concentrations of organic compounds were detected in borings L4-2 and L4-5. Seven metals were detected above MCLs. The most elevated concentrations of metals were found in borings L4-2 and L4-5. Groundwater was analyzed for the radiological parameters gross alpha, gross beta, and total radium. All three parameters were detected in groundwater at multiple Landfill No. 4 borings. The maximum concentration for all three radiological detected in any water sample collected from Landfills No. 1 through 4 originated from sludge dump boring L4-2. Chloride and sulfate indicator parameters were detected and the pH measurements in four borings were below the minimum of 6.5.

Monitoring wells 10, 10A, 10B, 11C, 46B, and 60C were sampled to determine the quality of USZ groundwater in the landfill. Eleven VOCs and eight SVOCs were detected sporadically in the landfill wells. Of the 19 organics detected, only seven compounds were detected more than once. Five organic compounds were detected above MCLs. All organic concentrations were below 100 µg/L, with the exception of one acetone value at 714 µg/L. Fifty-three percent of the organic detections originated from monitoring well 60C. The concentrations of organic contaminants in USZ monitoring wells were significantly below the concentrations detected in trench water samples from landfill borings. Cadmium, iron, lead, and manganese were detected at elevated concentrations. Chromium was detected in wells 10 and 10A at concentrations in excess of MCLs. Approximately, 47 percent of the detections for inorganic constituents originated from monitoring well 60C. Concentrations of some radiometric parameters were elevated in all six monitoring wells.

Monitoring well 10C was sampled to determine the quality of LSZ groundwater in the vicinity of Landfill No. 4. Three VOCs and two SVOCs were detected during 1992 sampling. No organics compounds were detected above MCLs. The organic compound with the highest concentration was dimethylphthalate at 16 µg/L. Barium and chromium were detected at concentrations above MCLs. None of the radiometric parameters were detected above MCLs.

An exposure assessment was performed to determine the potential human receptors and to analyze the potential exposure pathways at Landfills 1 through 4. Potentially exposed human populations were limited to industrial workers associated with Base operations. There were no sensitive subpopulations identified within the industrial site workers determined to represent the potentially exposed population at the sites. The only complete exposure pathways identified during the exposure assessment are inhalation of contaminated soil particles and inhalation of organic vapors from contaminated soil. In general, wildlife on the Base is typically tolerant of human activities and urban environments. No federal threatened or endangered species have been reported at the Base.

No interim remedial actions have been completed at Landfill No. 4, but the design for a 12-acre landfill cap was completed in September 1992 and is scheduled for construction in 1994. The design and construction of a leachate collection system is also planned as a future interim action.

9.0

9.0 Recommendations

The following paragraphs describe additional work recommended for the Phase II RFI. The additional work is required to fully characterize the nature and extent of contamination, and the risks to human health and the environmental at Landfill 4. Based on the location of this site, it will be more appropriate to investigate it as part of a group comprising several waste units in close proximity: RWDS 1030W, RWDS 1022E, RWDS 62598, Landfills 1, 2, and 3, the SP, and FTA1. Details of specific sampling needs will be presented in the work plan/sampling plan for the Phase II RFI.

Review of Landfills 1 Through 4 RI Report. Upon comparison of the summary tables of analytical results presented in Volume I of the RI report (USACE, 1993) and the available laboratory results in Volumes 3 and 4, numerous discrepancies were noted. A thorough review should be performed to resolve the discrepancies. The accuracy of these summary tables is crucial to the text of the RI. It was also noted that not all of the laboratory results were present to completely verify results listed in the summary tables.

In the previous investigations, data has been collected to characterize contaminated soils and groundwater within the landfill and investigate groundwater contamination around the perimeter of the landfill. A Phase II field investigation is recommended to perform the following tasks:

- Install additional monitoring wells in the HWBZ, USZ, and LSZ to characterize and determine the lateral and vertical extent of groundwater contamination originating from Landfill 4.
- Perform additional soil sampling in areas where elevated levels of contaminants were detected to determine the extent of contamination.
- Perform aquifer testing to obtain data to evaluate potential transport and migration of contaminants.
- Perform a baseline risk assessment to assess potential impacts to human health and the environment.

Installation of Additional Groundwater Monitoring Wells. The current well control adjacent to Landfill 4 is limited to six wells completed in the USZ (MW-10, 10A, 10B, 11C, 46B, and 60C) and one well completed in the LSZ (MW-10C). Monitoring well 46A is screened across the USZ and LSZ, and should be properly abandoned. Additional monitoring wells are needed to:

- Delineate and monitor the HWBZ and USZ separately as opposed to the USZ as currently defined in this report, which includes both zones.
- Determine the direction of localized groundwater flow within the HWBZ, USZ, and LSZ.
- Determine the vertical extent of contamination in the LSZ.

Three three-well clusters are recommended for installation around the landfill. Each well cluster will include wells completed in the HWBZ, USZ, and LSZ. One well cluster will be positioned in the northwest corner of the landfill east of Air Depot Boulevard. The remaining two well clusters will be located in the southwest and southeast corners of the landfill. Every monitoring well will have a 10-foot screen unless geologic conditions require shorter screens. All monitoring wells will be added during the Phase II RFI as part of the basewide groundwater investigation. The proposed well configuration along with the existing wells will provide adequate well control to determine groundwater flow direction and background versus downgradient contaminant concentrations within all three zones.

All existing and newly installed wells should be sampled and submitted for laboratory analysis of VOCs, SVOCs, metals, inorganic parameter, and radionuclides.

Aquifer slug testing should be performed on selected wells to obtain data to calculate groundwater flow rates. Slug tests should be performed at least in one upgradient and one downgradient well for each zone.

Due to the close proximity of Landfills 1 through 4 and other adjacent waste units, attempting to track the migration of specific contaminants at a distance from the perimeter of a single landfill may not be practical. In determining the lateral extent of contaminated groundwater associated with the landfills, it is recommended that the landfills and the adjacent waste units be considered as a single point source. Using this assumption, monitoring wells will be installed around the perimeter of these waste units to establish the lateral extent of contaminants in groundwater.

After the completion of the Phase II field investigation, a baseline risk assessment should be performed to evaluate potential threats to human health and the environment.

In addition, to fully evaluate the extent of soil contamination at this site it is recommended that site-specific soil background samples be collected during the Phase II RFI. This additional information along with the USGS background values should be used in the Phase II report to distinguish site-related from background concentrations in a statistically significant manner. During the development of the Phase II RFI work plan, the number of background samples to be collected, the location of the soil borings, and the soil analysis to be performed on the samples should be determined for EPA approval.

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10.0 References

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